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Predicting Toxic Waste Concentrations in Community Drinking Water Supplies Analysis of Vulnerability to Upstream Industrial Discharges

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PREDICTING TOXIC WASTE CONCENTRATIONS IN COMMUNITY DRINKING WATER SUPPLIES: ANALYSIS OF VULNERABILITY TO UPSTREAM INDUSTRIAL DISCHARGES

by

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16. ABSTRACT

In February, 1978 the Environmental Protection Agency (EPA) proposed amendments to the National Interim Primary Drinking Water Regulations to deal with the control of chloroform and synthetic organics in drinking water. Under the proposed rules, those utilities that could prove they were not "vulnerable" to the above parameters would be granted a variance from those regulations that would increase the cost of service.

By virtue of the variance procedure, EPA has concluded that there are variations in vulnerability. In November, 1979 the regulation regarding synthetic organics was dropped because of the difficulty in defining, let alone assessing a community's vulnerability. The purpose of this study was to predict toxic waste concentrations in community drinking water supplies along the Ohio and Kanawha Rivers between Charleston, West Virginia and Cincinnati, Ohio using QUAL-II, a water quality simulation model. More specifically, this study developed a toxic screening methodology as a means of closing the "loop" between water pollution control and water consumption.

The most important factors to consider in identifying vulnerable communities are: flow characteristics of the source of supply, potency and persitance of the pollutants, amount and timing of discharge of pollutants, storage times of utilities and relative location of point sources and community intakes.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and interplay among its components require a concentrated and integrated attack on the problem.

Research and development is the first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Muncipal Environmental Research Laboratory develops new and improved technology and systems (1) to prevent, treat, and manage wastewater, solid and hazardous waste, and pollutant discharges from municipal and community sources, (2) to preserve and treat public drinking water supplies, and (3) to minimize the adverse economic, solid, health, and aesthetic effects of pollution. This publication is a product of that research and is a most vital communications link between the research and the user community.

One of the major problems facing the U.S. Environmental Protection Agency is meeting the requirements of the Safe Drinking Water Act. The Act emphasizes the need to consider the raw water quality of the source of supply for community drinking water systems. The report presents results from a study on the development of a methodology to analyze the risks to communities from upstream industrial discharges. The toxic screening model allows the user to evalute the relative risks a community may face from (1) large unexpected spills and (2) background levels of typical daily discharges.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

In February, 1978 the Environmental Protection Agency (EPA) proposed amendments to the National Interim Primary Drinking Water Regulations to deal with the control of chloroform and synthetic organics in drinking water. Under the proposed rules, those utilites that could prove they were not "vulnerable" to the above parameters would be granted a variance from those regulations that would increase the cost of service.

By virtue of the variance procedure, EPA has concluded that there are variations in vulnerability. In November, 1979 the regulation regarding synthetic organics was dropped because of the difficulty in defining, let alone assessing a community's vulnerability. The purpose of this study was to predict toxic waste concentrations in community drinking water supplies along the Ohio and Kanawha Rivers between Charleston, West Virginia and Cincinnati, Ohio using QUAL-II, a water quality simulation model. More specifically, this study developed a toxic screening methodology as a means of closing the "loop" between water pollution control and water consumption.

The most important factors to consider in identifying vulnerable communities are: flow characteristics of the source of supply, potency and persitance of the pollutants, amount and timing of discharge of pollutants, storage times of utilities and relative location of point sources and community intakes, storage times of utilities and relative location of point sources and community intakes.

There is a great deal of sensitivity between the above factors. Contrary to conventional wisdom, one cannot assume that the most downstream utility faces the greatest risk and therefore be the most vulnerable. The total number of discharges upstream from a utility is not the proper criterion to judge vulnerability. Vulnerability depends on relative locations of intakes and outfalls and flow and persistance of the pollutants. Thus, it seems that the issue of community vulnerability is not a clear-cut issue of looking for the most downstream utility or modeling a few pollutants at average flow. Very detailed information about flow probabilities, pollutant characteristics, discharge flow and locations are required for identifying those communities at risk.

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CHAPTER I

INTRODUCTION

Statement of the Problem

In February, 1978 the Environmental Protection Agency (EPA) proposed amendments to the National Interim Primary Drinking Water Regulations to deal with the control of chloroform and synthetic organics in drinking water (Federal Register, 1978). Under the proposed rules, those utilities that could prove they were not "vulnerable" to the above parameters would be granted a variance from those regulations that would increase the cost of service.

In November, 1979 the regulation regarding synthetic organics was dropped because of the difficulty in defining, let alone assessing a community's vulnerability. The purpose of this study is to predict which communities are vulnerable to upstream industrial waste discharges along the Ohio and Kanawha Rivers between Charleston, West Virginia and Cincinnati, Ohio. More specifically, this study will develop a toxic screening methodology as a means of closing the "loop" between water pollution control and water consumption.

Only water utilities that utilize the river as their source of drinking water supply are considered in this analysis. Industrial waste discharges may include any number of natural or synthetic organic materials, heavy metals and bacteria of varying potency and concentration.

Through the use of a water quality simulation technique, this study will predict which communities in the case study area will be vulnerable to (1) large unexpected spills and (2) background levels of typical daily discharges, thus describing who is at risk, their relative levels of risk and the main factors contributing to the risk.

Significance of the Problem

Public and governmental concern about the dangers of pollution to the health of the people has increased significantly in the past decade. The complexity of the environment and the interplay between its components present an extensive and complicated problem to scientists.

Today, it seems that the old saying "Dilution is the solution to pollution," is really not quite so accurate as it once was. The former Environmental Protection Agency (EPA) Administrator Douglas M. Costle determined that the presence in drinking water of chloroform and other trihalomethanes (THM), and synthetic organic chemicals may have an adverse effect on the health of persons and therefore human exposure to these chemicals should be reduced (Federal Register, 1978).

Unfortunately, for most Americans, the problem of quantity often seems more pressing than the issue of quality of drinking water. The recent drought in the western part of the United States, specifically California, is a good example. However, many people do not realize that only 10 percent of the water this nation needs for its daily life is used for drinking purposes. The rest goes to agriculture and industry. It is the way in which this 90 percent is used which often creates the problems for that remaining 10 percent.

As an inadvertant by-product of our industrial growth, the commercial application of our scientific and technological progress, we are dumping a Niagra Falls of chemical compounds into our streams and rivers. Pollution of every description--pesticides from farms and orchards, municipal wastes, urban runoff--finds its way into the waterways of our nation, and thus into our drinking water. Despite natural dilution, we know that trace amounts of these contaminants elude even the best of conventional treatment and are consumed daily by millions of Americans. Of course, this problem is not unique to the United States; industrial nations around the globe are facing the same issue, and have yet to take the steps necessary to correct the problem (Hitch, 1978).

New dangers are now being perceived as threats to aquatic ecosystems and our drinking water. Materials such as trihalomethanes and synthetic organic chemicals (possible carcinogens) are replacing typhoid, cholera, dysentery, etc. as threats to public health. Synthetic organic chemicals may require hundreds of miles of river travel to be diluted and dispersed below "safe" levels of concentration. In fact, many substances such as pesticides may build-up in the food chain as time and distance increases from their point-of-entry into the river. Up to about 1974, questioning the purity of the water was something like taking on motherhood. Water was something that was unsafe to drink only when traveling in Mexico or out-of-the-way European villages.

This study is an attempt to assess the relative danger we place ourselves in, regarding the location and management of industry and our habitat.

Synopsis of Contents

This study brings together for the first time various types of data in an attempt to predict communities' vulnerability to upstream discharges of toxic wastes. Chapter II presents a discussion of the literature describing the scope of the contamination of our nation's drinking water sources. Contained in this section are reviews of the relevant issues regarding synthetic organic chemical contamination, human health considerations, sources of contamination and the proposed regulatory approach to deal with such contamination.

In Chapter III the multitude of factors affecting a community's vulnerability are outlined. The variability and number of components that ultimately determine vulnerability are such that they do not lend themselves to simple analyses. Rather, a framework is developed to take into account the various possibilities that can occur over space and time that can lead to varying levels of vulnerability for the same community. This chapter also describes the case study area, the methodologies employed and the selection of data.

Chapter IV presents the results from various simulations of the pollutants in the case study area over the various seasonal river flows, as well as typical daily discharges of pollutants and spills. Also presented are matrices of the simulated concentrations of pollutants for each of the communities whose source of drinking water is the river modeled.

Results indicate that communities do face varying levels of risk to upstream discharges of toxic wastes and that permits should be adjusted to account for various flows and that water treatment plants should make adjustments to handle the contaminants peculiar to their location.

Chapter V is the summary and conclusions based on the findings of the empirical analyses. Policy conclusions and suggestions for further research are also discussed.

CHAPTER II

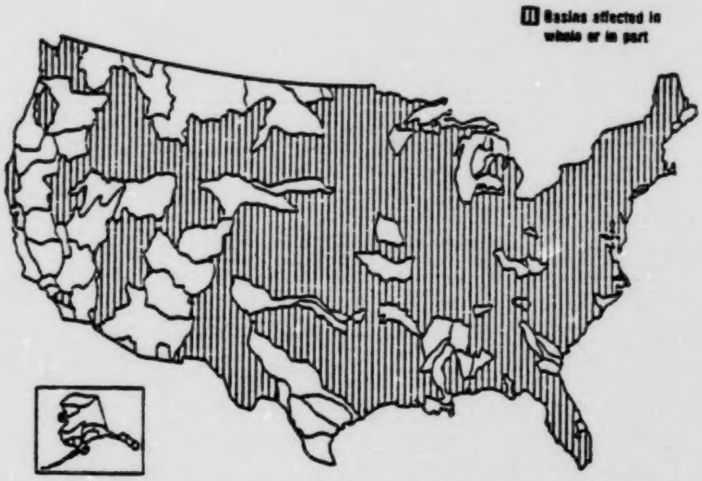
EVOLUTION OF AWARENESS AND RESPONSES TO THE DRINKING WATER SOURCE CONTAMINATION PROBLEM

Scope of the Problem

A considerable number of converging factors coalesced in 1971 and 1972 to cause drastic changes in controlling water pollution. Foremost among them was a general feeling that the nation's waters were not getting cleaner and that a shift in strategy was necessary. The third annual report of the Council on Environmental Quality concluded that while 27 percent of the nation's waters were polluted in 1970, the figure had risen to 29 percent by 1971. Another study showed that the efforts at that time were not keeping pollution from increasing (Lieber, 1975).

Industrial and municipal discharges affect water quality in most parts of the United States (Figure 1). The map somewhat overstates the extent of the water pollution in the United States because only part of the basin may be affected (CEQ, 1979). However, the real danger to human health from water pollution may be lurking beyond the traditional water quality indices. Hundreds of chemical substances have been identified as contributors to water pollution. At best, the knowledge regarding the effects of these chemicals and their synergistic action is fragmentary. Whereas a stream may exhibit improvements in fecal coliform levels, much more subtle and potentially dangerous synthetic organic pollutants may be a growing component in our drinking water sources. Jerome Horowitz, a leading water quality consultant, states that it is pointless to assess the immense water resources of a nation from a few hundred buckets of

Figure 1. Basins affected by industrial discharges, 1977



Source: U.S. Environmental Protection Agency. *National Water Quality Inventory: 1977 Report to Congress* (Washington, D.C.: U.S. Government Printing Office, 1978).

water sampled each month. He maintains that it is impossible to make even the most general statement about national water quality due to lack of reliable data (Tyler, 1981).

The Organics Problem

A study released by the Environmental Defense Fund (EDF) by Harris et al., (1976) attempted to statistically link cancer rates with New Orleans drinking water which contained hundreds of synthetic organics in trace quantities. This climaxed a growing suspicion since World War II that drinking water literally contains hundreds of synthetic organic chemicals, mostly in low concentrations (Dallaire, 1978). On the heels of this study came a suggestion from the EDF that Cincinnati's drinking water accounted for roughly 10 percent of the local cancer rate.

The contaminants identified to this point represent only about 15 percent by weight of the total organic matter in drinking water (EPA, 1978; NAS, 1977). Many contaminants defy identification and/or quantification given present analytical technology.

Less than 10 percent of the known contaminants have been adequately tested for adverse health effects. The National Cancer Institute (Table 1) identified 23 chemicals as known or suspected carcinogens, 30 chemicals as known or suspected mutagens, while 11 chemicals were identified as tumor promoters. Additionally some drinking water contaminants are known to cause birth defects, fetal deaths, or stunted growth (NAS, 1977).

Observed concentrations of specific contaminants range from approximately 5 parts per trillion (lowest detectable level) (EPA, 1977) to 1 part per million. However, concentration levels are meaningless without knowledge of potency. One part per trillion of one of the most potent

TABLE 1. CARCINOGENS, MUTAGENS, AND PROMOTERS FOUND IN UNITED STATES DRINKING WATER

Carcinogens and Suspect Carcinogens

- Benzo(a)pyrene
- Carbon tetrachloride
- Chloroform
- Vinyl chloride
- 1,4-Dioxane
- Methyl iodide
- DDE
- DDT
- Chlordane
- Lindane
- Dieldrin
- Benzene
- Vinylidene chloride
- Heptachlor
- 1,1,2-Trichloroethane
- 1,1,2-Trichloroethylene
- Bis (2-chloroethyl)ether
- Simazine
- Tetrachloroethylene
- Heptachlor epoxide
- Acrylonitrile
- Aldrin
- Butyl bromide

Mutagens and Suspect Mutagens

- 1,1,1-trichloroethane
- Bromomethane (methyl bromide)
- Methyl chloride
- Bromochloromethane
- Methylene chloride
- Bromoform
- Bromodichloromethane
- 2-Chloropropane
- 1,2-Dichloropropane
- 1-Chloropropene
- 1,2-Dichloroethane (recently shown to be carcinogenic by NCI)
- Bis(2-chloroisopropy)ether
- Chlorodibromomethane
- 1,3-Dichloropropene
- 2,6-Dinitrotoluene
- Dichloroacetonitrile
- Methylene bromide
- Chlordane
- Vinylidene chloride
- n-Butylbromide
- Bis(2-chloroethyl)ether
- Acrylonitrile
- Benzo(a)pyrene
- Methyl iodide
- Vinyl chloride
- 1,3-Butadiene
- 1,2-Bis(chloroethoxy)ethane
- Pyrene
- 1,1,2-trichloroethylene
- Tetrachloroethylene (Perchloroethylene)

List of Promoters

- Ortho-Cresol
- 2,4-dimethylphenol
- Phenol
- n-Dodecane
- Ecasane
- 2,4-dichlorophenol
- n-Decane
- Limonene
- Octadecane
- n-Tetradecane
- n-Undecane

Source: National Cancer Institute, May 1978.

carcinogens can cause as much cancer in rodents as one part per million of one of the weakest carcinogens, a millionfold range in potency (Page, Harris and Bruser, 1979).

Furthermore, the total risk associated with exposure to multiple carcinogens may be far greater than the sum of the risks posed by each chemical individually due to the synergistic interactions between carcinogens. Rodent studies have shown that exposure to promoters might enhance the carcinogenic effect of chemicals in drinking water compared to the effect of a lone carcinogen. In addition, the effects of drinking water contaminants may be increased by other exposures to carcinogens and promoters (e.g. air pollution, smoking), a particular problem for urban dwellers or those exposed to occupational carcinogens.

Human Health Considerations

Toxic wastes pose a potential threat to health today and in the future. The effects of exposure to carcinogens have a typically long latency; the time elapsing between exposure and clinical symptoms of the disease is often as much as twenty to forty years, depending upon the level of exposure (Page, Harris and Bruser, 1979).

In 1981 about 805,000 people will be diagnosed as having cancer (excluding skin cancer) with appoximately one-third of them surviving at least five years after treatment. Gastrointestinal and urinary tract cancers, to which organic drinking water contaminants have been most consistantly linked, comprise abut 30% of the total cancer illnesses and deaths annually (American Cancer Society, 1981).

By August 1979, 18 epidemiological studies and additional unpublished reports discussed possible relationships between cancer morbidity and mortality and drinking water supplies. The results of the studies are shown in Table 2. The table shows the statistically significant results of analysis by anatomical site. The statistically significant postive results are denoted by "M" for males and "F" for females and the statistically significant negative results are denoted by "-" before the "M" and "F". All of the studies were retrospective in design; sixteen were correlation studies and four, used a case-control approach. Four studies utilized cancer morbidity or incidence rather than mortality as a measure of disease frequency. The studies vary in sample size, cancer sites considered, factors selected as possible explanatory variables, parameters selected as indicators of water quality, and in the statistical techniques used for analysis, so caution must be used in comparing the results of one study with the results of another study.

There are several problems which make the results difficult to interpret: (1) there are limited water quality data on organics and other contaminants in the finished drinking water, and the data which exist cover less than five years; and (2) the water quality data are often from geographic areas other than those (usually counties) reporting cancer mortality data (Federal Register, 1979).

A study by Buncher et al., (1977) classified Ohio's 88 counties as either ground water or surface and using analysis of covariance compared average cancer mortality rates for ground and surface water counties. Mortality rates for stomach, bladder and malignant neoplasms were higher for white males in counties served by surface water supplies than in counties served by ground water supplies. Mortality rates for stomach neoplasms were higher for white females in surface water counties also. These differences in mortality rates were not attributable to other factors known to be associated with cancer death rates including

TABLE 2. STATISTICALLY SIGNIFICANT RESULTS OF EPIDEMILOGICAL CANCER STUDIES ON DRINKING WATER AND CANCER SITES(Federal Register, 1979)

No.	Author	Yr.	Oral	Esophagus	Stomach	Intestine (not rectum)	Rectum	Combined G.I.	Liver and Gallbladder	Pancreas	Respiratory (not lung)	Lung, trachae bronchi	Breast	Cervix	Uterus, ovary	Prostate	Bladder	Kidney	Combined Urinary	Lymphatic	Leukemia	Non-Hodgkins Lymphoma	Hodgkins	Thyroid	Brain	Larnyx	All Cancer	Study Type
1	Page, H.E.	74						M											M								M	
		76						F																				E
2	Tarone	75										M															M	E
3	Vasilenko	75			F	(studied females only)						F															F	E
4	DeRouen	75			F	M,F	M		M						F		M			M							F	E
5	Harris/	76		M	M			M		M							M		M								M	
	Reiches				F																						F	E
6	Buncher	75			M,F				F	F			F				M,F											E
7	Kuzma	77			M,F					F			F				M										M,F	E
8	McCabe	75	(total cancer and total mortality only)																								M,F	E
9	Cantor	78			F							F				M	M,F								M			E
10	Hogan	79	M	M	M,F	M,F	F		M	M							M,F							M,F				E
11	Salg	77		M	F	M	M,F	M				M	F				M			F			M,F			M,F	M	E
12	Kruse	77	(studied liver and kidney sites only)																									C-C
13	Mah	77	(eight sities studied - no statistically positive association/geographic and data analysis problems																									E
14	Alavanja	77		M	M	M	M	M				M					M		M								M	
		78			F			F											F								F	C-C
15	Wilkins	78							F								M		(liver, kidney & bladder only)									C-C
16	Rafferty, N.	79																										E
17	Brenniman	78				F		F	F										F									
						(Completed but results not useable)									(females only)													C-C
18	Tuthill[1]	78		M								F																E
	Tuthill[2]	79			M,F																							E

E - Ecological   C-C - Case-Control

urbanization, median income, population size, manufacturing activity and agricultural-forestry-fishery activities.

Alavanja et al., (1977) used X^2 analysis to study female gastrointestinal and urinary tract cancer mortality in seven New York counties (1968-1970). Initially, urban dwellers were at an equal risk with rural residents for gastrointestinal and urinary tract cancer mortality. When water type was taken into account, female residents receiving chlorinated water had higher relative risks then those receiving nonchlorinated water. Furthermore, when data were broken down by urban/rural residence, the risk for urban females residing in areas supplied with chlorinated water was greater than for their urban counterparts serviced by nonchlorinated water. The list of similar studies could go on for many pages, yet, the results are never the same. Most find some level of significant relationship but there are usually as many significant relationships as there are reports and methodologies. Unfortunately, the epidemiological studies do not distinguish the possible effects of THMs from those of synthetic organics which may have been present. While water has been chlorinated since the early 1900's, many synthetic organics are of recent origin. During the "chemical revolution" of the past 30 years, the annual production of synthetic organic chemicals increased from approximately 5 billion to 50 billion pounds per year. Many of these chemicals have never been found anywhere else in nature (Starr, 1980). Given a probable 20 to 40 year latency for most chemical carcinogens, it is likely that most of the effects of synthetic organics are not yet expressed in total U.S. cancer rates (Figure 2). Hence, currently observed excess cancers demonstrated in epidemiologic studies may be primarily the result of chlorination

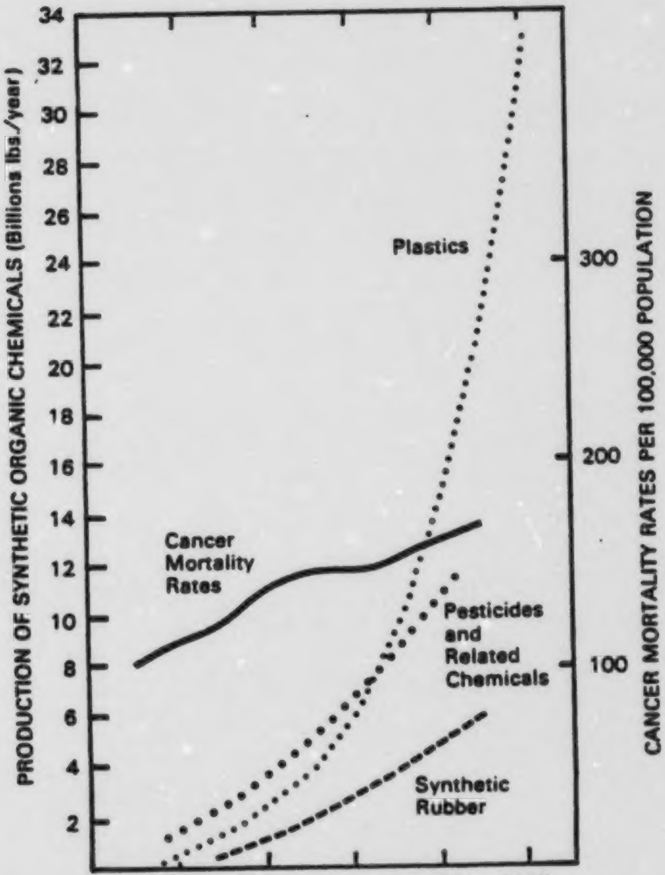


Figure 2. Cancer mortality rates and chemical production as a function of time (Harris et al., 1977)

by-products and may not reflect the risk from exposure to current levels of synthetic organics (Page, Harris and Bruser, 1979).

The evidence thus far is incomplete and the trends and patterns of association have not been fully developed. A causal relationship cannot be established by correlation studies. But when viewed collectively, the epidemiological studies completed thus far provide evidence for maintaining a hypothesis that there may be a health risk and that positive correlations may be due to an association between some constituents of drinking water and cancer mortality. Animal test data results alone can provide a firm basis for policy decisionmaking, if properly qualified. Additional epidemiological studies may provide evidence regarding the strength of the associations and the possibility of a causal relationship between drinking water and cancer mortality, and thus provide a stronger basis for further regulatory action.

Sources and Extent of Contamination

Available data show that compounds termed volatile synthetic organic chemicals (VOCs) occur in both surface and ground waters, which have become the repositories for the waste discharges of numerous industrial facilities and municipalities as well as urban and agricultural runoff (Federal Register, 1982).

At the time of the passage of the Safe Drinking Water Act of 1974, there were more than 12,000 chemical compounds known to be in commercial use with many more being added each year. The causes of synthetic organic chemical contamination are chronic and variable in nature. Table 3 compiled from Heuper (1964) lists some major contributors and representative compounds. Industrial discharges from point sources are regulated by the Federal Water Pollution Control Act Amendments' National Permit Discharge

TABLE 3. SOURCES OF CARCINOGENIC CHEMICALS FOUND IN WATER

Class of Compound	Source	Method of Introduction
Petrochemicals		
Oil(s) Polycyclic aromatics Methylated naphthalenes Kerosene etc.	Refinery waste, petrochemical plants, service stations, metal working plants, ships, carrier for pesticides, asphalted roads	Water discharge, spills, Rain, runoff direct application, spills
Coal tar		
Coal tar Pitch Creosote anthracene Aromatic hydrocarbons etc.	Coke ovens, tar distilleries, tar paper plants, wood treating, gas plants	Waste discharge, spills
Aromatic-amino and-Nitro Compounds		
Benzidine 4-aminodiphenyl Beta-napthylamine etc.	Dye and rubber plants, pharmaceutical plants, textile dying operations, plastics plants	Waste discharge, spills
Pesticides		
DDT Dieldrin Aramite Carbon tetrachloride Acetamide etc.	Manufacturing operations, use of pesticides	Waste discharge, spills, rainfall, runoff, settling from air

Elimination System. Despite this "control" of industrial discharges through the nationwide permit system, a certain amount of toxic pollutants continue to be discharged into surface waters. In addition, there is always the possibility of accidental (or otherwise) spills. So, at any time a large quantity of contaminants may thus enter a water supply system for which there is no water treatment equipment available to provide protection. Additionally, there are a number of non-point sources which may contribute highly toxic pesticides, and stormwater runoff carrying other potentially harmful substances is another source.

In analyzing drinking water in 80 cities, the EPA National Organics Reconnaissance Survey (NORS) (Symons et al., 1975) confirmed the widespread presence of many organics. NORS found as many as 129 organic compounds attributable to industrial, agricultural, and municipal sources, in finished drinking water supplies that passed through conventional (sedimentation, filtration, and chlorination) water treatment equipment. These compounds include carbon tetrachloride and 1,2-dichloroethane. One chemical was present in far higher concentrations than any other—chloroform, and its related family members the trihalomethanes. It has been shown (Rook, 1974 and Bellar, 1974) that chlorination of raw water in drinking water treatment plants produce such compounds as chloroform, carbon tetrachloride, chlorinated bromomethanes, and others. Table 4 lists some additional carcinogens from a limited survey in 1976 and 1977 (Page, Harris and Bruser, 1979). Domestic sewage plants also constitute a source of chlorinated hydrocarbons. These compounds are not significantly broken down by conventional waste treatment and pass through most plants unaffected. Chlorination of the domestic sewage results in the generation of a mixture of chlorinated hydrocarbons as well (Carlson, 1977).

TABLE 4. SELECTED CARCINOGENS* AND MUTAGENS FOUND IN 11-CITY SURVEY

Compounds	New Orleans	Miami	Seattle	Ottumwa	Philadelphia	Cincinnati	Tucson	N.Y.C.	Lawrence	Grand Forks	Terrace Park
*Benzene	X			X	X	X					
*Carbon Tetrachloride	X	X		X	X	X		X	X	X	X
*Bis(2-Chloroethyl)Ether	X				X						
*Chloroform	X	X	X	X	X	X	X	X	X	X	X
*1,2 Dichloroethane	X	X			X	X					
*Dieldrin	X	X	X	X		X					
*DDT, DDE	X										
*Heptachlor	X										
*Hexachlorobenzene	X										
*Hexachlorocyclohexane						X					
*Lindane (γ-BHC)						X				X	
*PCB						X					
*Tetrachloroethylene	X	X		X	X	X	X	X	X	X	
*Trichloroethylene	X	X		X	X	X			X		
*Vinyl Chloride		X			X						
Bromodichloromethane	X	X	X	X	X	X		X	X	X	X
Chlorobenzene	X	X	X	X	X	X		X	X	X	X
Chloromethylether	X										
Dibromochloromethane	X	X	X		X	X	X	X	X	X	X
1,3 Dichlorobenzene	X	X			X	X			X		
Dichloromethane	X	X			X	X		X	X	X	X
Methylene Chloride	X	X	X	X	X	X		X	X	X	X
Vinylidene Chloride	X	X			X	X			X		

The National Organics Monitoring Survey (NOMS, 1977) investigated 113 water systems and also found carbon tetrachloride, benzene, trichloroethylene, vinyl chloride, and styrene.

While surface waters subject to industrial contamination can contain a broad spectrum of synthetic organic chemicals, typically their concentrations would be in the low microgram per litre levels (e.g., less than 5 μg/l). Although only a small percentage of groundwater supplies have been found to be contaminated by one, two or more discrete compounds, their individual concentrations can be much higher (e.g., 100 to 1000 μg/l). While Table 5 shows a level as high as 35,000 μg/l of trichloroethylene, this is not to imply that most contamination incidents reflect concentrations of that magnitude. More commonly, contamination is found at less than 10 μg/l with smaller percentages in the 10-100 μg/l and in the 100-1000 μg/l range, respectively. The State data in particular reflects noticeably higher levels of contamination than the EPA surveys since the States sampling is generally a response to a specific problem or spill.

Contamination is most common in urban or industrial areas and is generally believed to be the result of improper disposal of hazardous wastes, industrial activities and/or sub-surface disposal system discharges (Federal Register, 1982). These and other data clearly demonstrate that synthetic organic chemical contamination in many of the nation's drinking water supplies is a reality. Although the proposed regulations distinguish between THMs and other organics, contaminated surface waters are likely to contain certain amounts of both types of organics.

TABLE 5. OCCURRENCE OF VOLATILE ORGANIC CHEMICALS IN DRINKING WATER

Survey	No. Sampled	No. Positive	Range of Positives
Trichloroethylene:			
State data[1]	2,894	810	Trace - 35,000 ug/L
NOMS[2]	113	28	0.2 - 49.0 ug/L
NSP[2]	142	36	Trace - 53.0 ug/L
CWSS[2]	452	15	0.5 - 210.0 ug/L
Tetrachloroethylene			
State data	1,652	231	Trace - 170.0 ug/L
NOMS	113	48	0.2 - 1.3 ug/L
NSP	142	24	Trace - 30.0 ug/L
CWSS	452	22	0.5 - 2.8 ug/L
Carbon Tetrachloride			
State data	1,659	166	Trace - 170.0 ug/L
NOMS	113	14	0.2 - 29.0 ug/L
NSP	142	37	Trace - 30.0 ug/L
CWSS	452	9	0.5 - 2.8 ug/L
Trichloroethane:			
State data	1,611	370	Trace - 401,300 ug/L
NOMS	113	19	0.2 - 1.3 ug/L
NSP	142	32	Trace - 21.0 ug/L
CWSS	452	19	0.5 - 650.0 ug/L
Dichloroethane:			
State data	1,212	65	Trace - 400.0 ug/L
Noms	113	2	0.1 -1.8 ug/L
NSP	142	2	Trace - 4.8 ug/L
CWSS	451	4	0.5 - 1.8 ug/L
Vinyl Chloride:			
State data	1,033	73	Trace - 380.0 ug/L
NOMS	113	2	0.1 - 0.18 ug/L
NSP	142	7	Trace - 76.0 ug/L
CWSS	Did not look for this compound		

---

[1] All ground water sources

[2] Surface and ground water sources. NOMS = National Organics Monitoring Survey. NSP = National Screening Program. CWSS - Community Water Supply Survey.

Regulatory Approach

The concept of standards for drinking water is not new. One of first historical references to drinking water standards is 4000 years old, recorded in Sanskrit (McDermott, 1973):

> It is directed to heat foul water by boiling and exposing to sunlight and by dipping seven times into it a piece of hot copper, then to filter and cool in an earthen vessel. The direction is given by the god who is the incarnation of medical science.

The federal authority for drinking water standards originated with the Interstate Quarantine Act of 1893, which authorized the surgeon general to make and enforce regulations to prevent the introduction, transmission, or spread of communicable diseases in the U.S. A provision in the act resulted in the promulgation of the Interstate Quarantine Regulations of 1894. In 1912 the first water-related regulation—the prohibition of the use of the common drinking water cup on interstate carriers—was adopted. Since that time a series of drinking water regulations has been issued. The dates and major implications of the regulations are shown in Table 6.

The last set of drinking water standards was issued in 1962. In 1969 a technical committee was established to write a new set of standards. The committee's work was completed in 1972, but the standards were held up pending the passsage of the Safe Drinking Water Act of 1974.

The Safe Drinking Water Act

Title 14 of the Public Health Service Act, entitled "Safety in Public Water Systems," is commonly called the Safe Drinking Water Act (Public Law 93-523). It applies to all public water systems as defined in the act, including federally owned or maintained water systems (Clark, 1978).

TABLE 6. DRINKING WATER STANDARDS

Date of Standard	Major Feature
1914	The first bacteriological performance standard was introduced.
1925	Standards were modified to include chemical standards.
1942	Bacteriological samples were taken from distribution systems.
1946	Standards were made generally applicable to all water supplies in the United States.
1962	Requirement was made that water supply systems be operated by qualified personnel. Recommended maximum concentration limits were added for: alklybenzene sulfonate barium cadmium carbon chloroform extract cyanide nitrate silver

The act defines contaminants, maximum concentration levels, primary drinking water regulations, secondary drinking water regulations, public water systems, supplies, agency heads, and so forth. Some of the definitions are as follows:

> Contaminant--Any physical, chemical, biological, or radiological substance or matter in water.
>
> Maximum Contminant Level (MCL)--The maximum concentration of a contaminant allowable in water delivered to a user.
>
> Public Water System--A water system that has at least 15 connections and serves at least 25 individuals.

The more than 200,000 public water systems specifically included under PL 93-523 serve cities, towns, communities, Indian communities and federal facilities. Public water systems include those in service stations, hotels and other facilities where the public has access to water. Of primary interest to the USEPA are the approximately 40,000 community systems.

Primary drinking water regulations specify contaminants that may have an adverse effect on health. They define a maximum contaminant level or treatment technique and contain criteria and procedures to assure a safe supply. Secondary drinking water guidelines specify maximum contaminant levels that are necessary to protect the public welfare and include such items as taste, odor and appearance. These may vary acccording to regional circumstances and are not federally enforceable, but are guidelines (Clark, 1978).

The proposed amendments to the National Interim Primary Drinking Water Regulations in February, 1978, had they been implemented, were intended to protect the public health from THMs and VOCs.

The proposed regulations were to consist of two parts:

(1) a maximum contaminant level (MCL) of .10 mg/l or 100 parts per billion (ppb) for total trihalomethanes including chloroform, which occur in drinking water as the result of the interaction of the chlorine applied for disinfection with the organic substances which naturally occur in raw water, and

(2) a water treatment technique such as granular activated carbon (GAC) in the water treatment process for the control of synthetic organic chemicals associated with industrial pollution and urban and agricultural runoff contaminating drinking water supplies (Federal Register, 1978).

EPA concluded that the latter, a treatment technique (such as GAC) should be used for synthetic organic chemicals since it would not be technically or economically feasible to monitor for the presence of the thousands of synthetic organic chemicals that may have an adverse impact on human health. GAC has the additional advantages of removing THMs and unpleasant tastes and odors resulting from organic contaminants and their interactions with chlorine.

Initially, only those water utilities serving 75,000 people would have to install GAC within 3 1/2 years of the regulation being promulgated. This would involve only 1% of the public utilities (390 out of 40,000) in the U.S., but they would account for approximately 100 million people. The regulation could be expanded to include those utilities ranging from 10,000 to 75,000 people served affecting 2700 more utilities and 62 million more people. Due to economies-of-scale, the already expensive GAC technique could terribly strain small community budgets.

Variance Procedures

Although the GAC treatment technology was initially applicable to all community water systems with 75,000 or more customers, a system could have requested a variance from the regulations. To receive a variance under the Safe Drinking Water Act of 1974, a utility would have to demonstrate that their system (i.e. the people) was not vulnerable to significant synthetic organic chemical contamination. Thus, the expensive GAC technique would not be necessary. By the use of this variance procedure, only those utilities whose raw water source and/or present treatment system leave their customers vulnerable to synthetic organic chemical contamination would have to install the expensive and technologically sophisticated GAC treatment technology.

In order to be granted a variance, a system would submit two basic types of information. First—the system must provide information with respect to those point and non-point sources of pollution that would be likely sources of synthetic organic chemical contamination for the system's drinking water supply. This is done because upstream polluters are considered to be one of the most important contributors to chemical contamination in drinking water. Also, the identification of various pollution sources would serve as a significant link between drinking water programs of various agencies. This should encourage systems to look for sources of pollution as a planning tool similar to the "bubble concept" used in air pollution regulations. Second--water utilities must provide information with respect to the locations of the particular dischargers and the characteristics of their wastes. Information such as "type" and "concentration" of chemicals in the normal discharges as well as the potential for accidental spills from railroads, terminal facilities, bridges, and firms must be provided.

This information would be needed to give the variance issuing authority the ability to assess the likelihood that a system's raw water supply may be contaminated by synthetic organic chemicals on a case-by-case basis, based upon local conditions (Federal Register, 1978).

Objection to Proposed Regulation

There were a combination of factors that ultimately led to the proposed GAC regulation being dropped. Following the announcement of the proposed regulations in February of 1978 there were many public hearings, and cost estimates that resulted in lawsuits trying to block promulgation of the regulations. EPA cost estimates of implementing the GAC technology clashed with the higher water industry figures that predicted costs to consumers would double. An independent consultant failed to account for the effects of inflation over the span of time encompassing the discussion and had to adjust their cost estimates upward approximately 25% thus losing creditability as to their accuracy. It was assumed that EPA could identify those utilities requiring GAC. However, no method that was defensible in court with specific guidelines was forthcoming. Therefore, the GAC portion of the regulation was dropped while the THM portion of the amendments became law on November 29, 1979.

CHAPTER III

EMPIRICAL METHODOLOGY

Introduction

By virtue of the variance procedure, EPA has concluded that there are variations in vulnerability. In order to predict which communities are vulnerable to upstream discharges of industrial wastes, data are needed on quantity and quality of waste discharged, location of discharge, location of community water intakes and storage capacity, flow and velocity of the river, watershed land use, slope, soil type, vegetation and institutional arrangements that vary over space and time.

This chapter presents the multitude of factors that can have a significant impact on a drinking water source based on a case study area. Further discussion concentrates on many of the estimations of the relevant water quality parameters and data inputs necessary to produce meaningful results.

Case Study Area

The study area selected for analysis includes those communities that utilize the Ohio River as their drinking water source and the major industrial dischargers along the Ohio and Kanawha Rivers between Charleston, West Virginia and Cincinati, Ohio. Major industrial dischargers are designated as contributing at least one million gallons daily of wastewater or 100 pounds per day of BOD_5 to the Ohio River (Dames & Moore). Together, the 16 major dischargers in the case study area account for approximately 500 million gallons daily of wastewater as compared to the 20 minor industrial dischargers that account for approximately 3 million gallons daily.

The case study area was chosen because of the variety of utilities and possible sources of contamination. The case study area was also designed to take into account the Kanawha River Basin in West Virginia since it has been a source of chemical contamination in the past.

Figure 3 presents the case study area. The Kanawha River enters the Ohio River at River Mile (RM) 265.6. Pittsburgh is situated at RM 0 and the Ohio River confluence with the Mississippi River at Cairo, Illinois is at RM 981. The last utility in the study area, Newport, Kentucky is located at RM 463.5. This 200 mile segment of river between the Kanawha River and Cincinnati, Ohio is almost directly in the center of the basin and represents the heartland of industrial, agricultural, silvicultural and mining activities. This area includes 20 counties in 3 states: Ohio, West Virginia and Kentucky. There are 12 highway and 6 railroad bridges spanning the Ohio River along with numerous freight terminal facilities.

The Kanawha River Valley has been one of the most heavily polluted reaches in the United States for many years. Due to the location in the Kanawha Valley of the second largest petro-chemical industrial complex in the country, over two billion gallons per day of water are used in the valley, principally for cooling purposes. River Mile 32 to 74 on the Kanawha River is the locale of the maximum degradation of the stream's water quality. The condition is caused by continuous loadings of municipal and industrial wastes far beyond the river's natural potential for recovery. All of the Kanawha River dischargers in the analysis are located within this stretch of river (West Virginia, 1974).

The Huntington-Portsmouth area along the Ohio River main stem has approximately 75 direct industrial dischargers. The products from such

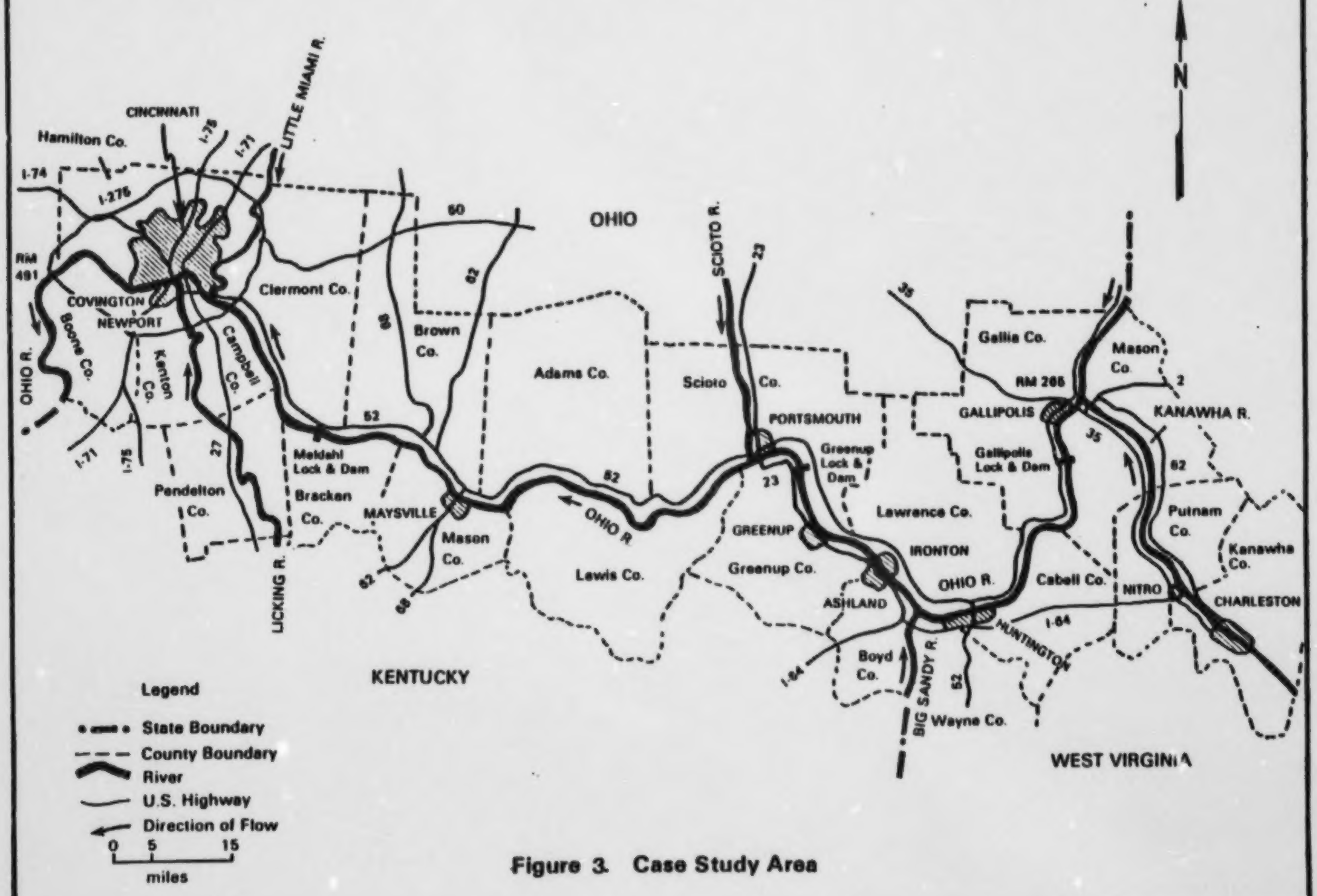


Figure 3. Case Study Area

operations include chemicals, iron castings, food products, steel products and coke. The most prominent industrial activity is chemical followed by steel products. From Portsmouth to Cincinnati there are no major industrial dischargers and it is in this area that the basin changes from a rugged terrain to that of gently rolling rich farmland (Dames & Moore, 1975). There are approximately 69 direct dischargers in the Cincinnati area but are located downstream from the water utilities and are not included in this analysis. Because all of the major components for point and non-point sources of pollution are present within this reach, it is felt that this section of river will be representative of a wide variety of impacts and data requirements which can reasonably be extrapolated to most other basins in the country.

Data Sources

The first step in the analysis was to provide an inventory and description of existing point sources and communities using the Ohio and Kanawha Rivers as their source of drinking water. In order to make a complete and thorough analysis of a community's vulnerability to water pollution, non-point sources of pollution as well as the point sources should be considered. However, there are tremendous gaps in the land use data in the study area, thus pre-empting any attempts to model runoff water quality. To combat the lack of data and tremendous complexity of the land use-water quality interface, only the major industrial dischargers and their wastes are considered in this analysis, although the techniques described herein could be used to model both minor discharges and nonpoint run off. Such an effort would require an effort beyond the scope of this report.

Table 7 is a listing of the major dischargers in the case study area. Data for this table came from Dames & Moore, the state of West Virginia Department of Natural Resources and NPDES Permits from the various EPA regional offices in Philadelphia, Atlanta and Chicago.

As can be seen in Table 7, SIC Codes 2812, 2819, 2821, 2865, 2869 and 3311 are represented. The Standard Industrial Classification Codes (SIC Codes) are divided into Major Groups and then into Industry Numbers. In this study, only Major Groups 28 and 33 are involved. Table 8 briefly describes the above SIC Codes (U.S. OMB, 1975).

Typical waste stream data for each industry type in the case study area were supplied by the Permit Compliance Division of the EPA in Washington, D. C. Each SIC Code was assigned discharge values in parts per billion based on Best Available Control Technology, for the relevant contaminants coming from the industries' production processes.

Water utility data (Table 9) were acquired through personal conversations with utility personnel. Storage time indicates how long the system could operate if the intakes would be closed. In the event of a spill, the intakes would be closed to prevent the high concentration of pollutants from entering the system. Thus, the larger the storage capacity of a utility, the less vulnerable to spills the utility would be.

Flow and velocity data were acquired from the United States Geological Survey Water Resources Data, the Ohio River Valley Sanitation Commission (ORSANCO) and detailed data on depth, flow and velocity for each milepoint were generated from a U.S. Army Corps of Engineers water quantity routing model called HEC-II (U.S. Army Corps of Engineers, 1980).

TABLE 7

INVENTORY OF MAJOR INDUSTRIAL DISCHARGERS IN CASE STUDY AREA

	River Mile	Discharger No	Name of Discharger	County, State	Industrial Discharge (CFS)	SIC Code
Kanawha River						
	69.2	1.	E. I. DuPont de Nemours Belle,	Kanawha W. VA	3.87	2869
	56.2	2.	Union Carbide S. Charleston,	Kanawha W. VA	15.48	2869
	54.7	3.	FMC Inorganic S. Charleston,	Kanawha W. VA	4.33	2812
	48.2	4.	Union Carbide Inst. Institute,	Kanawha W. VA	8.92	2869
	42.7	5.	FMC Viscose Nitro,	Putnam W. VA	50.62	2819
	42.7	6.	FMC Organic Nitro,	Putnam W. VA	5.88	2869
	42.6	7.	Monsanto Nitro,	Putnam W. VA	19.50	2869
Ohio River						
	270.0	8.	Stauffer Chemical Gallipolis Ferry,	Mason W. VA	.85	2819
	280.4	9.	Goodyear Tire & Rubber Apple Grove,	Mason W. VA	.48	2821
	318.4	10.	Allied Chemical South Point,	Lawrence OH	118.19	2819
	320.0	11.	Allied Chemical Ashland,	Boyd KY	9.29	3312
	325.0	12.	Allied Chemical Ironton,	Lawrence OH	.33	3312
	325.0	13.	Allied Chemical Ironton,	Lawrence OH	15.48	2812
	325.0	14.	Armco Steel Ashland,	Boyd KY	66.19	3312
	332.2	15.	E. I. DuPont de Nemours Wurtland	Greenup KY	18.11	2821
	336.5	16.	U.S.S. Chemicals Haverhill,	Lawrence OH	1.24	2865

TABLE 8

INVENTORY OF SIC CODES IN CASE STUDY AREA

Major Group 28 - CHEMICALS AND ALLIED PRODUCTS

Code	Title	Description
2812	Alkalies and Chlorine	Establishments primarily engaged in manufacturing alkalies, chlorine, soda ash, caustic soda ash and other basic inorganic chemicals.
2819	Industrial Inorganic Chemicals, Not Elsewhere Classified	Establishments engaged in manufacturing inorganic salts, chromium, magnesium, mercury, silver, nickel and elemental fluorine among many others.
2821	Plastic Materials, Synthetic Resins and Nonvulnerizable Elastomers	Important products include phenolic and other tar resins, vinyl resins, petroleum polymer resins, polyesters, and pthalic anhydride resins.
2865	Cyclic Crudes, Cyclic Intermediates, Dyes and Organic Pigments	Important products of this industry include among many others derivatives of benzene, toluene, napthalene, anthracene, synthetic organic dyes, synthetic organic pigments and coal tar crudes.
2869	Industrial Organic Chemicals, Not Elsewhere Classified	Important products not classified elsewhere include non-cyclic organic chemicals, solvents such as trichloroethylene plasticizers and esters.

Major Group 33 - PRIMARY METAL INDUSTRIES

Code	Title	Description
3312	Blast Furnances, Steel Works and Rolling Mills	Establishments primarily engaged in manufacturing ferroalloys, pig iron and in hot rolling iron into basic shapes such as strips, bars and tubing

TABLE 9

WATER UTILITY DATA

River Mile	Utility	Storage Time	Population Served
268.5	Gallipolis, OH	2.0 days	11,000
304.3	Huntington, W.VA	3.0 hours	115,000
319.6	Ashland, KY	22 hours	45,000
327.0	Ironton, OH	2.5 days	15,000
334.7	Greenup, KY	2.5 days	1,500
355.5	Portsmouth, OH	1.5 days	50,000
408.4	Maysville, KY	1.0 days	9,500
462.8	Cincinnati, OH	3.0 days	860,000
462.9	Kenton Co., KY	6.0 days	30,000
463.5	Newport, KY	3.5 hours	15,000

The water quality simulation model (QUAL-II) source code was supplied by the North Carolina Computing Center of EPA. User support came from the EPA Environmental Research Laboratory in Athens, Georgia and Gates and Associates, a consulting firm.

Ambient Water Quality Criteria for the protection of human health were supplied by the Environmental Criteria Assessment Office (ECAO) of EPA. The Water Quality Criteria suggest concentrations of pollutants that could be harmful to human health. Volatilization decay rates for the pollutants being simulated were the result of extensive calculations based on literature reviewed and data supplied by the Exposure Assessment Section of EPA (See Appendix A)

Obviously, many sources were tapped for the analysis. Much of the data are merely guidelines or suggestions based on very preliminary investigations such as the typical waste stream data or Water Quality Criteria for health effects. One of the criticisms regarding defining a "vulnerable" utility was the availability of data, and this is a valid argument. However, after much effort the necessary data for at least a preliminary analysis is available, although not in a manner readily accessible to water utility personnel attempting such a modeling effort singularly. This type of analysis would be best attempted by State, Federal or Regional Authority personnel. One implication that can be drawn is that if such an analysis can be done over a tri-state area and spanning a myriad of institutional arrangements, then similar vulnerability studies could be done on smaller, less complicated watersheds within a region or state.

Identification of Variables

Pollution may impair the quality of water, land, or air or all three simultaneously, especially in the case of a spill. A land spill of a nonvolatile, toxic substance generally has less impact on the environment than a spill of a highly volatile, toxic substance or a substance that has entered a waterway. When water contamination is involved, the fluidity of the medium favors the transport of highly hazardous substances over wide areas with possible dangerous consequences. In general, once a pollutant enters a waterway, it can not be contained. If the material is insoluble, retainment and adsorption techniques can be used, but it may be impossible to retain soluble materials. In the case of daily allowable discharges, there of course is no attempt to contain the pollutants once they enter the stream. Volatile compounds are also lost to the atmosphere and may create both water and air pollution problems.

The processes that influence the fate of pollutants in the aquatic environment are outlined in Figure 4 (Dawson et al., 1970). Natural processes include physical distribution mechanisms involving dispersion and water currents and biological and chemical transformations. The biological concentration of pollutants and various physical and chemical processes include adsorption, precipitation and ion exchange (Zajic, 1978).

The vulnerability of the communities is a function of the:

(1) amount of upstream contaminant discharged into the river,

(2) flow characteristics of the river,

(3) physical persistance of the discharges,

(4) toxicity of the individual discharges, and

(5) storage capability.

Additionally, a large spill or number of discharges that join together to form a slug may have an acute health effect as opposed to a longer term effect of small everyday doses of a contaminant.

Model Selection

To address factors 1, 2 and 3 above, that affect a community's drinking water source, a water quality routing model will be utilized. The model will simulate industrial discharges of toxic materials downstream based on the river's characteristics and the physical properties of the wastes.

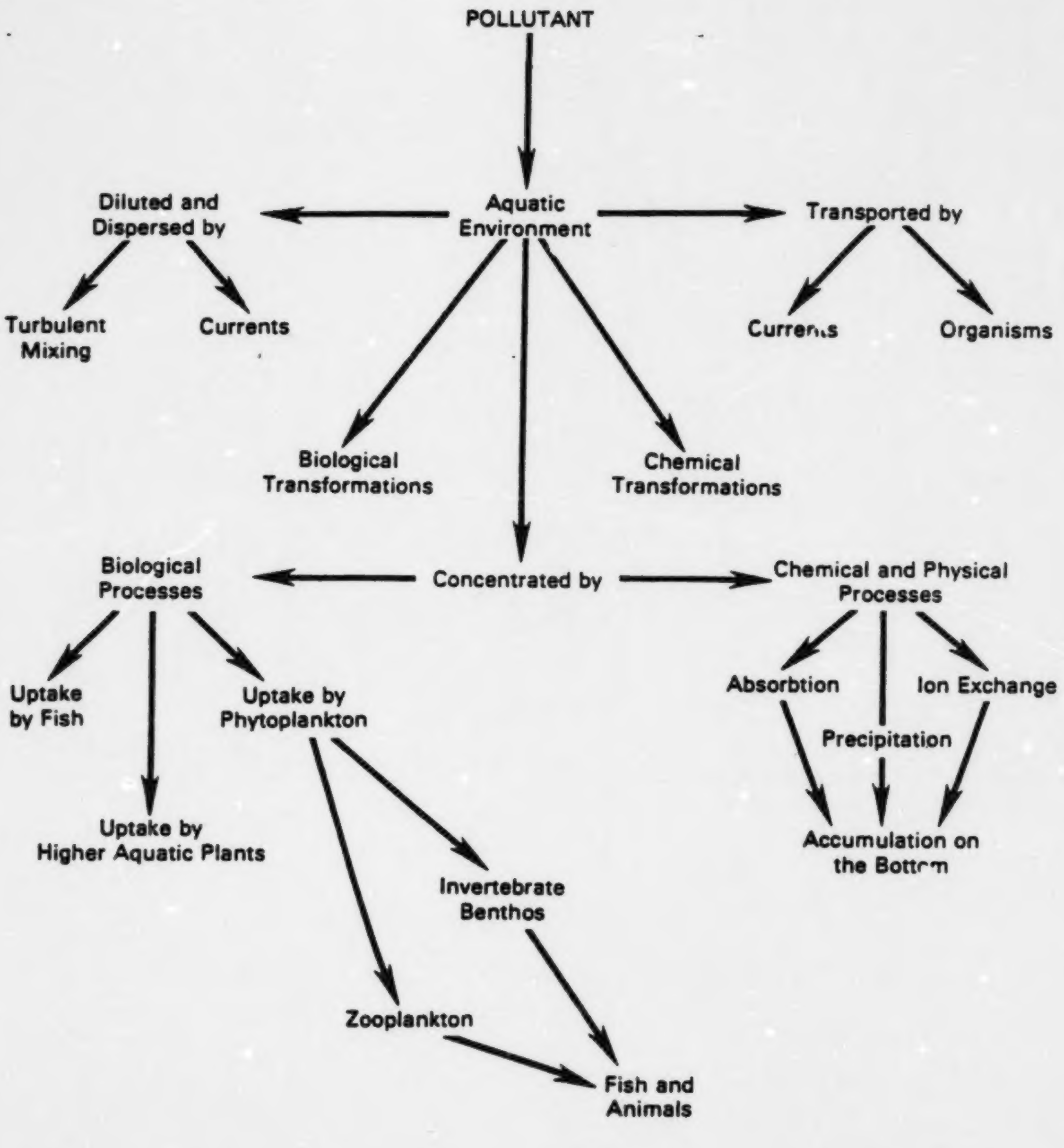


Figure 4. Environmental Distribution Processes Affecting Pollutants

There are a variety of water quality models available to users such as EXAMS, WQRRS and QUAL-II that are supported by EPA or the U.S. Army Corps of Engineers. QUAL-II is one of the most widely used, calibrated and supported. Based on many personal conversations with modelers along with the availability of the program and compatible computer facilities, QUAL-II appeared to be the best model available at the time (see Appendix A).

Qual-II is written in FORTRAN IV and can simulate up to 13 water quality constituents in any combination desired. Constituents which can be simulated are:

(1) Dissolved Oxygen,
(2) Biochemical Oxygen Demand,
(3) Temperature,
(4) Algae as Chlorophyll a,
(5) Ammonia as Nitrogen,
(6) Nitrite as Nitrogen,
(7) Nitrate as Nitrogen,
(8) Dissolved Orthophosphate as Phosphate,
(9) Coliforms,
(10) Arbitrary Nonconservative Constituent and
(11) Three Conservative Constituents.

The program allows for multiple discharges, withdrawals, tributary flows and incremental inflows. QUAL-II can be used to study the impact of waste loads (magnitude, quality, and location) on instream water quality. The magnitude and quality characteristics of non-point waste loads can be assessed when used in tandem with sampling programs but that is beyond the scope of this research. Various options of the program also make it possible to trace the water quality impact of slug loadings, such as a spill, or seasonal or periodic discharges (Roesner, 1981).

Data Requirements

A variety of data is required depending on what constituents are being modeled. Data required for all operations include the following in english or metric units:

1. Stream Flow
2. Stream Velocity

The above data would be required for each stream and tributary modeled. Small tributaries could also be included simply as a point load. Cross-sectional stream geometry such as used in HEC-2 could be utilized in place of flow and velocity.

Model Set-up

The first step in producing output is to decide which segments of a stream are to be modeled. A schematic diagram of a hypothetical stream system is laid out in Figure 5. Once the data such as stream geometry, number and location of waste inputs or withdrawals is known, the stream can be broken down into reaches, which are portions of the stream system with nearly uniform hydraulic characteristics. Reaches, headwaters, waste discharges, or withdrawals and junctions are ordered sequentially from the uppermost point of the system. The final step is to decide on the degree of resolution that is required. This decision is based on some knowledge of how the river or constituents behave. The more change, the

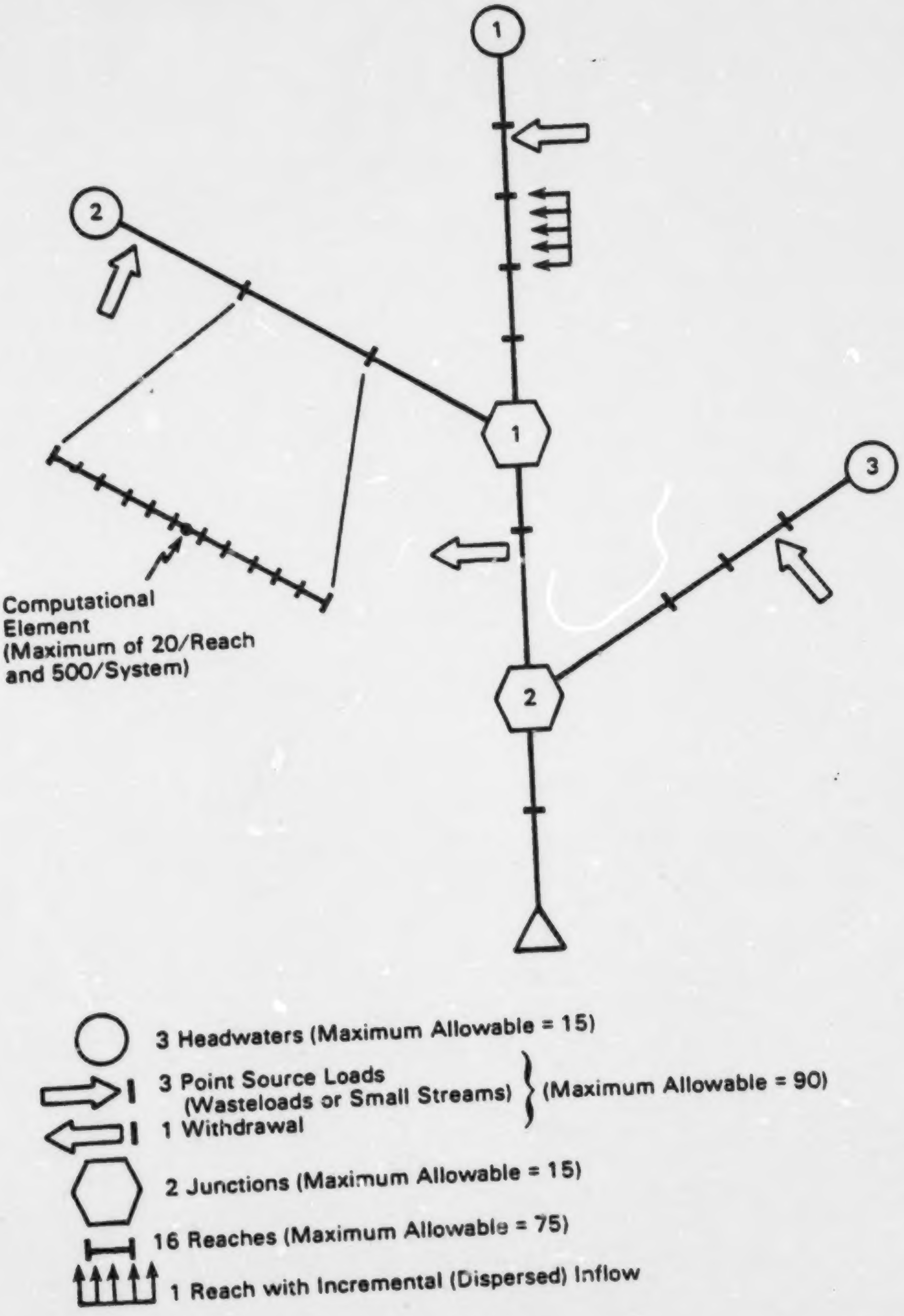

1
2
3
1
2
Computational Element (Maximum of 20/Reach and 500/System)
3 Headwaters (Maximum Allowable = 15)
3 Point Source Loads (Wasteloads or Small Streams)
(Maximum Allowable = 90)
1 Withdrawal
2 Junctions (Maximum Allowable = 15)
16 Reaches (Maximum Allowable = 75)
1 Reach with Incremental (Dispersed) Inflow

Figure 5. A Schematic Diagram of a Hypothetical Stream System

greater the resolution required. In most cases, each reach is broken down into computational elements from one-half to two miles in length.

The pollutants to be simulated are based on the court case Natural Resources Defense Council (NRDC) V. Train [8 E.R.C. 2120 (D.D.C. 1976)]. The 1977 Amendments to the Clean Water Act (CWA) adopted a consent decree list of " priority pollutants" as the list of toxic substances to be given primary emphasis in the implementation of the CWA (Table 10).

TABLE 10.

CONSENT DECREE LIST OF PRIORITY POLLUTANTS

(Arbuckle, 1979)

Acenaphthene
Acrolein
Acrylonitrile
Aldrin/Dieldrin
Antimony and compounds*
Arsenic and compounds
Asbestos
Benzene
Benzidine
Beryllium and compounds
Cadmium and compounds
Carbon tetrachloride
Chlordane (technical mixture and metabolities)
Chlorinated benzenes (other than dichlorobenzenes)
Chlorinated ethanes (including 1,2-dichloroethane, 1,1,1-ethane and hexachloroethane)
Chloroalkyl ethers (chloromethyl, chloroethyl, and mixed ethers)
Chlorinated naphthalene
Chlorinated phenols (other than those listed elsewhere; includes trichlorophenols and chlorinated cresols)
Chloroform
2-chlorophenol
Chromium and compounds
Copper and compounds
Cyanides
DDT and metabolites

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*The term "Compounds" shall include organic and inorganic compounds.

TABLE 10 (cont'd)

Dichlorobenzenes (1,2-,1,3-, and 1,4-dichlorobenzenes)
Dichlorobenzinine
Dichloroethylenes (1,1- and 1,2-dichloroethylene)
2,4-dichlorophenol
Dichloropropane and dichloropropene
2,4-dimethylphenol
Dinitrotoluene
Diphenylhydrazine
Endosulfan and metabolities
Endrin and metabolites
Ethylbenzene
Fluoranthene
Haloethers (other than those listed elsewhere; includes chlorophenyl-phenyl ethers, bromophenylphenyl ether, bis (dichloroisopropyl) ether, bis-(chloroethoxy) methane and polychlorinated diphenyl ethers)
Halomethanes (other than those listed elsewhere; includes methylene chlorid methylchloride, methylbromide, bromoform, dichlorobromomethane, trichlorofluoromethane, dichlorodifluoromethane)
Heptachlor and metabolites
Hexachlorobutadiene
Hexachlorocyclohexane (all isomers)
Hexachlorocyclopentadiene
Isophorone
Lead and compounds
Mercury and compounds
Naphthalene
Nickel and compounds
Nitrobenzene
Nitrophenols (Including 2,4-dinitrophenol, dinitrocresol)
Nitrosamines
Pentachlorophenol
Phenol
Phthalate esters
Polychlorinated biphenyls (PCBs)
Polynuclear aromatic hydrocazrbons (including benzanthracenes, benzopyrenes, benzofluoranthene, chrysenes, dibenzanthracenes, and indenopyrenes)
Selenium and compounds
Silver and compounds
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)
Tetrachloroethylene
Thallium and compounds
Toluene
Toxaphene
Trichloroethylene
Vinyl chloride
Zinc and compounds

QUAL-II will be used to simulate the applicable "priority pollutants" for each of the firms listed in Table 7, according to the Permit Compliance Division of EPA. The daily emissions will be routed downstream through the case study area. Tributary and incremental inflow will be taken into account by the model based on USGS and ORSANCO flow data. Seasonal flows will be considered since dispersion and decay will vary greatly, based on volume and time-of-travel of the rivers.

The VOCs will be simulated as nonconservative constituents based on derived decay rates. However, many of the VOCs exhibit such low decay rates they resemble metals and inorganics (conservative constituents) that are degraded only by dispersion and advection. It is assumed that there are zero levels of the contaminants in the rivers modeled as they enter case study area. However, in reality there are bound to be various contaminants already in the Ohio River coming down from Pittsburgh, outside the case study area, therfore one can see that a community's vulnerability could be altered simply by the designation of the study area.

Once the priority pollutants are simulated using QUAL-II, the estimated concentrations at the water utility intakes will be compared to the Water Quality Criteria to see if the estimates exceed the Criteria, and therefore constitute a possible health hazard to the community.

The Criteria are pursuant to section 304 of the Clean Water Act (CWA). EPA is required to periodically review and publish criteria for water quality accurately reflecting the latest scientific knowledge.

The criteria must contain two essential types of information: (1) scientific data on the effects of pollutants on public health and welfare, aquatic life and recreation, and (2) quantitative concentrations or qualitative assessments of the pollutants in water which will generally ensure water quality to support a specified use. The criteria are meant only as guidelines and have no legal authority (Federal Register, 1980).

The Criteria take into account toxicity, carcinogenicity or organolepticity (taste and odor) of the pollutants, thus accounting for the fourth major variable listed previously.

The Water Quality Criteria for toxicity and taste and odor indicate the general population would be affected by consuming water with a pollutant reaching the standard, such as 3,770 ug/L of cyanide (a toxic) or 300 ug/L phenol (an odor causing agent). A tenfold buffer is incorporated in the toxic and organoleptic standards to take into account the more sensitive or susceptible consumers such as the very young or old, pregnant or ill. Therefore, it is possible that segments of a population could be affected by 377 ug/L and 30 ug/L of cyanide and phenol respectively.

The carcinogenic data are estimates of incremental risks associated with exposures from suspected carcinogens in drinking water. For example, it is assumed that a person is at the .00001 risk level of developing cancer in his or her lifetime by drinking 2 litres of water with 6.6 ug/L of Benzene daily. The only no risk level for carcinogens is zero concentration. Risk is assumed to be linear, however promoters and synergism among the pollutants could actually increase the risk levels. Table 11 displays the pollutants applicable to the industries in the case study area, the individual pollutant discharge per outfall using the Best Available Control Technology (BAT) and their Water Quality Criteria.

TABLE 11

WATER QUALITY CRITERIA FOR THE PROTECTION OF HUMAN HEALTH

Priority Pollutant Name and Category	Priority Pollutant No.	BAT Discharge (ppb)	Criteria
I. PESTICIDES			
Acrolein	1	100	T= 325 ug/L
Aldrin	2	1	C= 0.74 ng/L
α-BHC	3	5	C= 22 ng/L
β-BHC	4	5	C= 134 ng/L
γ-BHC	5	5	C= 186 ng/L
DDE	9	1	C= 0.24 ng/L
Dieldrin	11	1	C= 0.71 ng/L
α-Endosulfan	12	1	T= 74 ug/L
Endrin	15	1	T= 1.0 ug/L *
Heptachlor Epoxide	18	1	C= 2.0 ng/L
II. METALS AND INORGANICS			
Antimony	22	500	T= 146 ug/L
Arsenic	23	50	C= 22 ng/L
Beryllium	25	50	C= 68 ng/L
Cadmium	26	500	T= 10.0 ug/L *
Chromium	27	500	T= 50.0 ug/L *
Copper	28	500	O= 1.0 mg/L
Cyanide	29	1000	T= 3.77 mg/L
Lead	30	500	T= 50.0 ug/L *
Mercury	31	50	T= 144 ng/L
Nickel	32	500	T= 632 ug/L
Selenium	33	50	T= 10.0 ug/L *
Silver	34	50	T= 50.0 ug/L *
Thallium	35	50	T= 13.0 ug/L
Zinc	36	500	O= 5.0 mg/L
III. PCB's AND RELATED COMPOUNDS			
PCB-1221	38	1	C= 0.79 ng/L
PCB-1232	39	1	C= 0.79 ng/L
PCB-1242	40	1	C= 0.79 ng/L
PCB-1248	41	1	C= 0.79 ng/L
PCB-1254	42	1	C= 0.79 ng/L

TABLE 11 (Cont'd)

Priority Pollutant Name and Category	Priority Pollutant No.	BAT Discharge (ppb)	Criteria
IV. HALOGENATED ALIPHATICS			
Chloromethane	46	100	C= 1.9 ug/L
Dichloromethane	47	100	C= 1.9 ug/L
Chlorodibromomethane	48	100	C= 1.9 ug/L
Dichlorobromomethane	49	100	C= 1.9 ug/L
Tribromomethane	50	50	C= 1.9 ug/L
Chloroform	51	100	C= 1.9 ug/L
Carbon Tetrachloride	52	50	C= 4.0 ug/L
Trichlorofluoromethane	53	100	C= 1.9 ug/L
Dichlorodifluoromethane	54	100	C= 1.9 ug/L
1,2-Dichloroethane	57	100	C= 9.4 ug/L
1,1,1-Trichloroethane	58	100	C= 18.4 ug/L
1,1,2-Trichloroethane	59	100	C= 6.0 ug/L
1,1,2,2-Tetrachloroethane	60	50	C= 1.7 ug/L
Trichloroethene	65	100	C= 27 ug/L
Tetrachloroethene	66	50	C= 8.0 ug/L
1,3-Dichloropropene	68	100	T= 87 ug/L
Hexachlorobutadiene	69	25	C= 4.47 ug/L
V. ETHERS			
Bis(chloromethyl)ether	71	100	C= 0.038 ng/L
Bis(2-chloroethyl)ether	72	100	C= 300 ug/L
Bis(2-chloroisopropyl)ether	73	100	T= 34.7 ug/L
Vinyl Chloride	74	100	C= 20.0 ug/L
VI. MONOCYCLIC AROMATICS			
Benzene	78	50	C= 6.6 ug/L
Chlorobenzene	79	50	O= 20.0 ug/L
1,3-Dichlorobenzene	81	50	T= 400 ug/L
1,4-Dichlorobenzene	82	25	T= 400 ug/L
Ethylbenzene	85	50	T= 0.71 mg/L
Nitrobenzene	86	50	O= 30 ug/L
Toluene	87	50	T= 14.3 mg/L
2,4-Dinitrotoluene	88	50	C= 1.1 ug/L
VII. PHENOLS AND CRESOLS			
Phenol	90	50	O= 0.3 mg/L
2-Chlorophenol	91	50	O= 0.1 ug/L
2,4-Dichlorophenol	92	50	O= 0.3 ug/L
2,4,6-Trichlorophenol	93	25	O= 2.0 ug/L
Pentachlorophenol	94	10	O= 30.0 ug/L
2,4-Dinitrophenol	97	25	T= 70.0 ug/L
2,4-Dimethylphenol	98	50	O= 400 ug/L

TABEL 11 (Cont'd)

Priority Pollutant Name and Category	Priority Polluant No.	BAT Discharge (ppb)	Criteria
VIII. PTHALATE ESTERS			
4,6-Dinitro-o-cresol	100	25	T= 13.4 ug/L
Dimethylpthalate	101	25	T= 313 mg/L
Diethylpthalate	102	25	T= 350 mg/L
Dibutylpthalate	103	25	T= 34 mg/L
IX. POLYCYCLIC AROMATIC HYDROCARBONS			
Acenaphthene	107	10	O= 20 ug/L
Acenaphthylene	108	10	C= 28 ng/L
Anthracene	109	10	C= 28 ng/L
Benzo(a)anthracene	110	1	C= 28 ng/L
Benzo(ghi)anthracene	113	1	C= 28 ng/L
Chrysene	115	1	C= 28 ng/L
Fluoranthene	117	10	T= 42 ng/L
Fluorene	118	10	C= 28 ng/L
Phenanthrene	121	10	C= 28 ng/L
Pyrene	122	1	C= 28 ng/L
X. NITROSAMINES			
Diphenylnitrosamine	124	5	C= 49 ug/L
Acrylonitrile	129	100	C= 580 ug/L

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* existing standard
O = Organoleptic
T = Toxic
C = Carcinogenicity at the 10^{-5} risk level

Table 12 displays which industry type by SIC Code is responsible for the priority pollutants to be simulated. Goodyear Tire and Rubber Company at RM 280.4 and E. I. DuPont de Nemours at RM 332.2 are classified 2821 which discharges nearly all the priority pollutants found in the case study area, thus accounting for much of the vulnerability experienced by the City of Greenup as will be shown later.

TABLE 12

PRIORITY POLLUTANTS TO SIMULATE

Discharger No.	3,13	5,8,10	9,15	19	1,2,4,6,7	11,12,14
			SIC Code			
Pollutant No.	2812	2819	2821	2865	2869	3312
01			X			
02			X			
03			X			
04			X			
05			X			
09			X			
11			X			
12			X			
15			X			
18			X			
22	X	X	X			
23	X	X	X	X		X
25			X			X

TABLE 12 (Cont'd)

Discharger No.	3,13	5,8,10	9,15	16	1,2,4,6,7	11,12,14
	SIC Code					
Pollutant No.	2812	2819	2821	2865	2869	3312
26	X	X	X	X		X
27	X	X	X	X		X
28	X	X	X	X	X	X
29		X	X	X		X
30	X	X	X	X		X
31	X		X	X		X
32	X		X			X
33	X		X			
34	X	X	X			X
35	X	X				
36	X	X				X
38						
39						
40						
41			X			
42						
44			X			
46			X			
47	X		X			
48			X			
49			X			

TABLE 12 (Cont'd)

Discharger No.	3,13	5,8,10	9,15	16	1,2,4,6,7	11,12,14
	SIC Code					
Pollutant No.	2812	2819	2821	2865	2869	3312
50			X			
51	X		X	X	X	
52			X			
53			X			
54			X			
57			X		X	
58			X			
59			X			
60			X			
65	X		X		X	
66	X		X	X	X	
68			X			
69			X			
71			X			
72			X			
73			X			
74			X			
78			X	X	X	
79			X			
81			X			
82			X			

TABLE 12 (Cont'd)

Discharger No.	3,13	5,8,10	9,15	16	1,2,4,6,7	11,12,14
			SIC Code			
Pollutant No.	2812	2819	2821	2865	2869	3312
85			X	X	X	X
86			X			
87	X		X	X		X
88			X			
90	X		X	X	X	X
91			X			
92			X			
93			X			
94			X	X	X	
97			X			
98			X	X	X	
100			X			
101			X			
102	X		X		X	
103	X		X		X	X
107			X			
108			X			
109			X			

TABLE 12 (Cont'd)

Discharger No.	3,13	5,8,10	9,15	16	1,2,4,6,7	11,12,14
	SIC Code					
Pollutant No.	2812	2819	2821	2865	2869	3312
110			X			
113			X			
115			X			
117			X			
118			X			
121			X			
122			X			
124			X			
129			X			

The utilities' water storage capabilities will be evaluated as to their ability to serve their customers during a spill when the intakes would be closed thus accounting for the fifth facet affecting vulnerability. Most of the priority pollutants that pass through each utility's water treatment system do so unaffected, and some may even be increased. The simulated concentrations of toxic and organoleptic pollutants will be compared to the relevant Water Qualtiy Criteria. Each utility will be assesed as to the number and magnitude of violators of the Criteria.

Total risk from exposure to all the carcinogenic pollutants will be calculated for each utility. The expected death rate per 100,000 will be calculated from the risk levels for each pollutant. In this manner, one can assess the various levels of risk for each utility to carcinogens in the drinking water and which toxic or organoleptic pollutants are a threat to the consumers.

In the event of a spill, the storage time of each utility will be compared against the time the spill takes to pass the utility. A spill will also be simulated at high, low and average flows to evaluate seasonal conditions and possible acute health effects.

Conceptual Representation of Case Study Area

Figure 6 schematically represents the case study area, the waste loads, tributaries, junction and headwaters involved in the water quality modeling. The results of the simulations appear in Chapter 4.

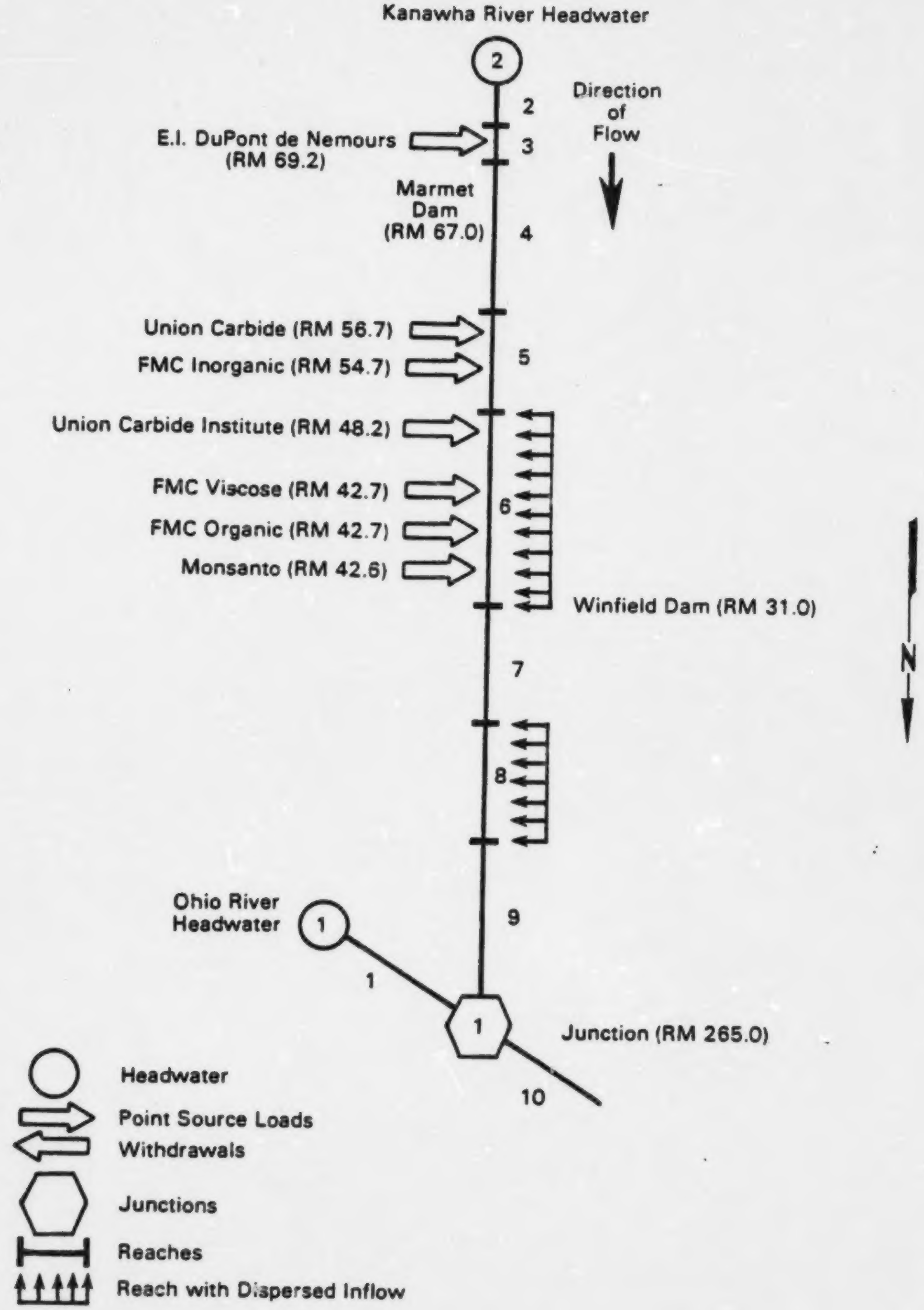

Figure 6. Schematic of Case Study Area

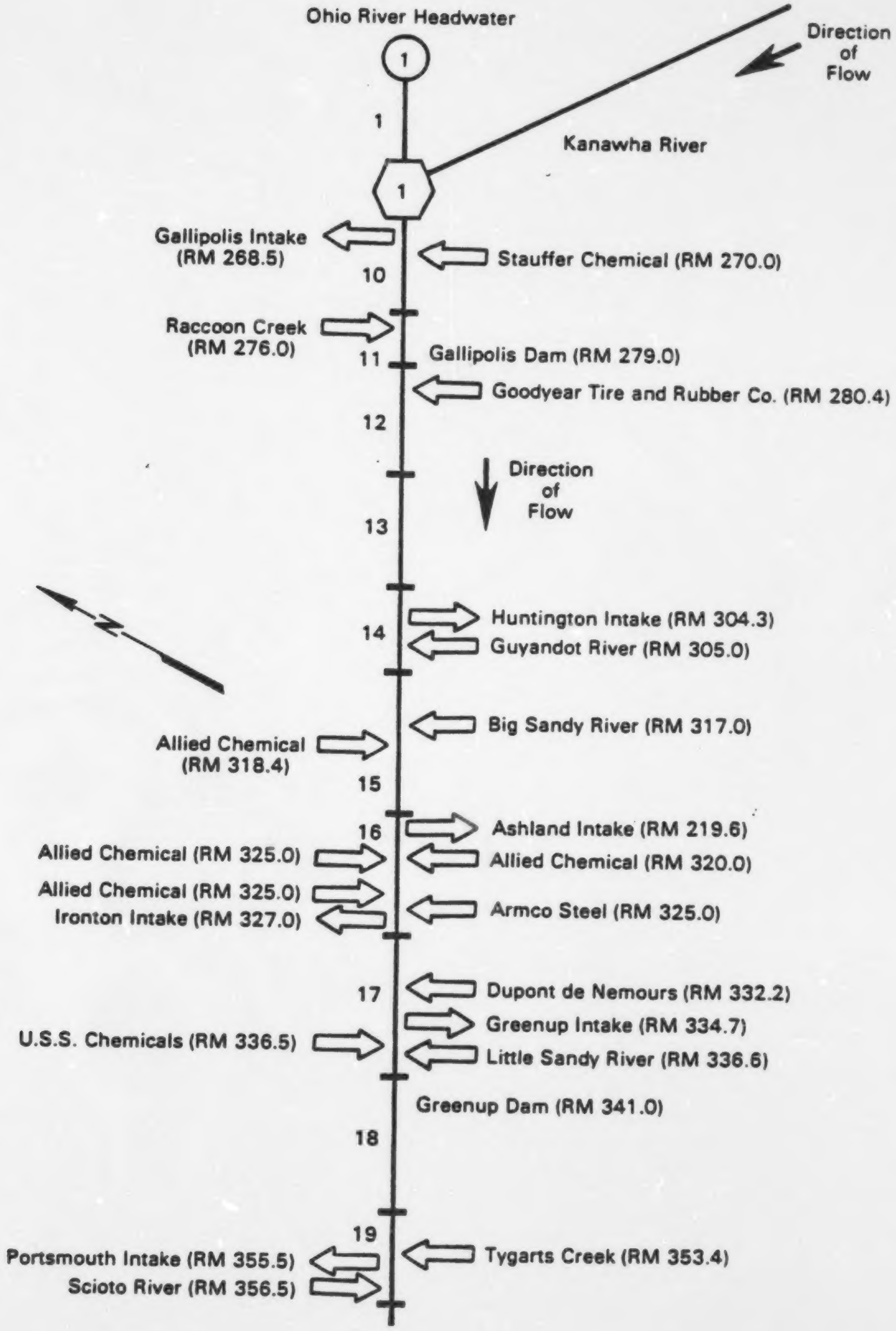
Ohio River Headwater
1
1
Kanawha River
Direction of Flow
1
Gallipolis Intake (RM 268.5)
Stauffer Chemical (RM 270.0)
10
Raccoon Creek (RM 276.0)
Gallipolis Dam (RM 279.0)
11
Goodyear Tire and Rubber Co. (RM 280.4)
12
Direction of Flow
13
N
Huntington Intake (RM 304.3)
14
Guyandot River (RM 305.0)
Big Sandy River (RM 317.0)
Allied Chemical (RM 318.4)
15
Ashland Intake (RM 219.6)
16
Allied Chemical (RM 325.0)
Allied Chemical (RM 320.0)
Allied Chemical (RM 325.0)
Ironton Intake (RM 327.0)
Armco Steel (RM 325.0)
17
Dupont de Nemours (RM 332.2)
Greenup Intake (RM 334.7)
U.S.S. Chemicals (RM 336.5)
Little Sandy River (RM 336.6)
Greenup Dam (RM 341.0)
18
19
Portsmouth Intake (RM 355.5)
Tygarts Creek (RM 353.4)
Scioto River (RM 356.5)

Figure 6. (Continued)

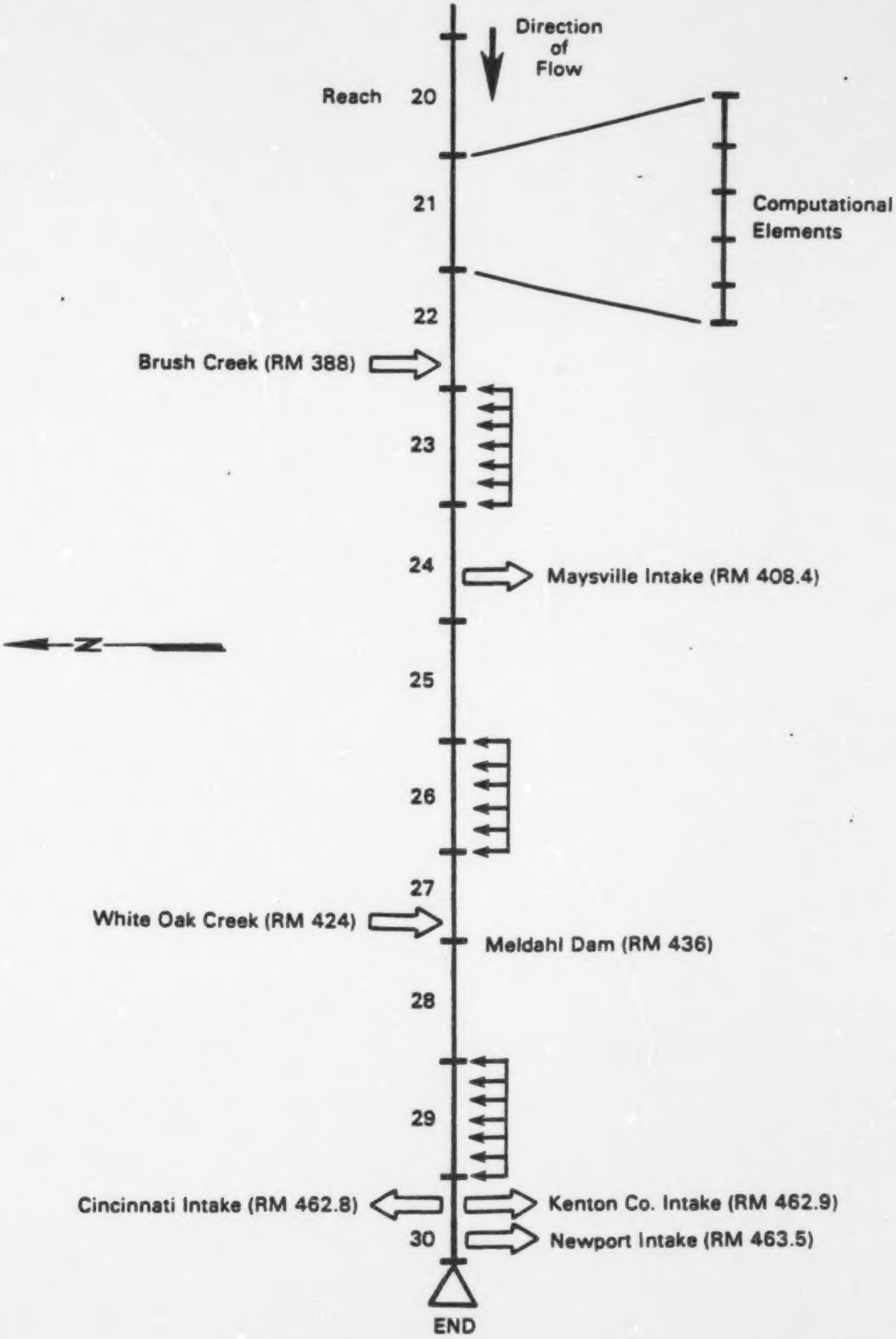

Figure 6. (Continued)

CHAPTER IV

RESULTS

Introduction

There are many critical issues involved in assessing a community's vulnerability to upstream discharges of toxic wastes. Of these factors, the physical parameters are uppermost in importance and variability. These parameters include the following:

(1) Biological transformation of pollutants,

(2) Chemical transformation of pollutants,

(3) Uptake by plants and animals,

(4) Chemical absorbtion and

(5) Flow characteristics.

Presently, there is a small but growing body of knowledge regarding the first four physical parameters listed above for the priority pollutants. These parameters could be very important to the fate and transport of pollutants, but the information and models to incorporate the data are in their infancy still being developed. Flow characteristics have traditionally been modeled and well calibrated, and are still the prime factor in determining the ultimate fate and transport of pollutants in the water.

Table 13 presents monthly data for the Ohio River at Cincinnati, Ohio for the years 1970 to 1975. As can be seen, there is a great deal of variability. Daily Ohio River flows varied from 13,000 cubic feet per second (cfs) to 460,000 cfs. Flood stage occurs at 444,000 cfs. The depth and velocity of a river determines how much longitudinal, horizontal and vertical dispersion and/or decay takes place on the pollutants.

TABLE 13

OHIO RIVER FLOW CHARACTERISTICS AT CINCINNATI, OHIO (River Mile 462.8)
(X 1,000 CFS)

	Month											
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1970	111.43	202.48	147.93	234.46	108.02	48.81	40.11	35.57	32.60	46.58	113.07	154.52
1971	127.45	230.40	200.15	68.95	143.37	55.98	38.80	42.24	64.90	33.73	34.85	127.26
1972	178.86	175.68	254.72	281.89	129.53	106.65	113.07	52.12	25.63	48.22	181.72	282.23
1973	110.03	155.08	198.94	226.84	184.73	97.70	47.67	34.38	19.42	33.10	103.67	161.14
1974	281.71	135.65	205.57	189.67	121.16	141.99	31.00	35.60	77.34	32.98	74.15	175.95
1975	197.96	267.64	316.32	185.92	155.15	91.40	32.32	32.28	89.12	94.40	73.85	NO DATA
MEAN	168.21	194.49	220.61	197.96	140.33	90.42	50.50	38.70	51.50	48.17	96.89	180.22
S.DEV	66.73	49.14	52.79	65.19	24.93	31.34	31.24	7.37	29.39	23.16	49.80	59.69

YEARLY AVERAGE = 123.15

As well be shown later, river flow is very critical to the risk assessment of a utility.

Flow Scenarios

In order to assess the vulnerability of communities to daily discharges of toxic wastes, three scenarios were created to account for variations in flow. Using QUAL-II, the applicable priority pollutants discharged in the case study area (81 out of the 129 priority pollutants) were simulated at average, high and low flows. Average flow was set at 125,000 cfs, high flow at 220,000 cfs and low flow at 35,000 cfs. The high and low flow values were chosen to reflect the highest and lowest monthly average flows. As volume of water increases, so does the mean velocity in the river channel. Table 14 displays the various flow conditions and the time-of-travel calculated by QUAL-II in the case study area to the last utility Newport, Kentucky.

TABLE 14

HYDRAULIC CHARACTERISTICS FOR DAILY DISCHARGE SCENARIOS

SCENARIO	CFS (X 1,000)	TIME-OF-TRAVEL (DAYS)
HIGH FLOW	220.00	2.4
AVERAGE FLOW	125.00	4.1
LOW FLOW	35.00	15.0

An analysis of daily flows for the six years of flow data indicated that the average number of days of having a volume greater than 220,000 cfs continuously was 7.2 days. The average number of continuous days with a volume less than 35,000 cfs was 14.1, with some cases where an entire month exhibited flows well below the low flow scenario. Of course in this large case study area there is bound to be precipitation in a watershed that could affect river flow many miles downstream, but it seems reasonable to assume that flows around 35,000 cfs will be present during the summer months enough to conservatively simulate the fate of pollutants at this reduced volume.

For toxic and organoleptic pollutants, the flow scenarios are critical as to whether a Water Quality Criteria is exceeded. Vulnerability to carcinogens are evaluated over years of exposure to pollutants in the drinking water, therefore carcinogenic risk levels were only estimated at average flows. However, in the event of a spill, the flow characteristics can be important even to carcinogens since very high concentrations of carbon tetrachloride, for example, can have an acute health effect. Additionally, regulatory agencies may desire to use higher or lower than average flows to increase safety factors. Contrary to conventional wisdom, low flows may not necessarily exhibit higher concentrations of pollutants due to decreased dilution than higher flows as will be demonstrated for the volatile organic contaminants later.

QUAL-II Simulations of the Organoleptic Pollutants

The vulnerability of utilities depend on the flow characteristics of the Ohio River and the pollutant's physical properties. Utilites can be vulnerable to different pollutants at different flows. Table 15 displays the concentration of the 11 organoleptic pollutants for the 10 utilities in the case study area at average flow. As can be seen, none of the pollutants exceed the Criteria. Neither do any of the pollutants exceed 10% of the Criteria value that would indicate sensitive members of the population would be affected.

For Tables 15-17 and 19-21, one can read across the matrix and track a particular pollutant as it travels downstream or read down the matrix of a particular utility to get a snapshot of the concentrations of the pollutants at that utility.

Table 16 displays the simulated concentrations of the organoleptic pollutants at high flow. As one would expect, the concentrations are lower, due to greater dilution by the greater volume of water. However, there is an exception, the chlorobenzene concentration for Cincinnati, Kenton County Water District No. 1 and Newport, Kentucky. Although the concentration (denoted by #) of 1.62 parts per trillion (ppt) of chlorobenzene does not approach a safety level to be concerned about, it does however exceed the 1.45 ppt level for average flow in Table 15. Chlorobenzene is a volatile organic contaminant with a calculated decay rate of .55/day. At average flow, Chlorobenzene takes 4.1 days to pass the Cincinnati area intakes while at high flow it only requires 2.4 days of travel. This extra time during the average flow scenario allows more of the chlorobenzene to decay than at high flow. The speed at which the Ohio River travels during a high flow period brings the pollutants to the intakes before any substantial decay can occur, thus the seemingly contradictory higher levels of chlorobenzene downstream at high flow.

TABLE 15

ORGANOLEPTIC POLLUTANT CONCENTRATIONS AT AVERAGE FLOW

POLLUTANT	CRITERIA (ug/L)	DECAY RATE/day	CONCENTRATIONS AT UTILITIES IN ug/L							
			GALLI.	HUNT.	ASHL.	IRON.	GREE.	PORT.	MAYS.	CINC. AREA
Copper	1000.0	Cons.	.620	.620	.150	1.540	1.640	1.520	1.490	1.340
Zinc	5000.0	Cons.	.310	.320	.890	1.280	1.280	1.190	1.170	1.050
Chlorobenzene	20.0	.5500	.000	.0002	.00015	.00014	.00829	.00617	.00337	.00145#
Nitrobenzene	30.0	.0600	.000	.00026	.00022	.00022	.00890	.00840	.00740	.00616
Phenol	3000.0	.0250	.03144	.03088	.03062	.06996	.07895	.07236	.06916	.06037
2-Chlorophenol	.1	.0550	.000	.00027	.00022	.00022	.00891	.00806	.00746	.00625
2,4-Dichlorophenol	.3	.0100	.000	.00027	.00023	.00023	.00897	.00827	.00803	.00716
2,4,6-Trichlorophenol	2.0	.0250	.000	.00013	.00011	.00011	.00447	.00410	.00392	.00342
Pentachlorophenol	30.0	.0100	.006	.00597	.00508	.00506	.00692	.00638	.00620	.00552
2,4-Dimethylphenol	400.0	.0600	.0271	.02596	.02171	.02144	.03048	.02755	.02536	.02110
Acenaphthene	20.0	.2000	.000	.00005	.00004	.00004	.00174	.00149	.00118	.00081

Cons. = No Volatilization

TABLE 16

ORGANOLOEPTIC POLLUTANT CONCENTRATIONS AT HIGH FLOW

POLLUTANT	CRITERIA (ug/L)	DECAY RATE/day	CONCENTRATIONS AT UTILITIES IN ug/L							
			GALLI.	HUNT.	ASHL.	IRON.	GREE.	PORT.	MAYS.	CINTI AREA
Copper	1000.0	Cons.	.350	.350	.650	.870	.920	.860	.840	.760
Zinc	5000.0	Cons.	.180	.180	.500	.720	.720	.670	.660	.590
Chlorobenzene	20.0	.5500	.000	.00013	.00010	.00010	.00484	.00394	.00275	.00162#
Nitrobenzene	30.0	.0600	.000	.00015	.00013	.00013	.00504	.00461	.00436	.00376
Phenol	3000.0	.0250	.01812	.01794	.01780	.04007	.04523	.04165	.04027	.03569
2-Chlorophenol	.1	.0550	.000	.00015	.00013	.00013	.00504	.00461	.00431	.00379
2,4-Dichlorophenol	.3	.0100	.000	.00015	.00013	.00013	.00506	.00468	.00457	.00410
2,4,6-Trichlorophenol	2.0	.0250	.000	.00008	.00006	.00006	.00253	.00233	.00225	.00200
Pentachlorophenol	30.0	.0100	.00341	.00340	.00290	.00290	.00395	.00365	.00356	.00320
2,4-Dimethylphenol	400.0	.0600	.01612	.01574	.01330	.01321	.01838	.01678	.01588	.01369
Acenaphthene	20.0	.2000	.000	.00003	.00002	.00002	.00100	.00088	.00076	.00059

Cons. = No Volatilization

Consequently, one can see in Table 17 that the chlorobenzene concentrations during low flow at Ironton, Maysville and Cincinnati Area intakes exhibit the same or lower concentrations than the average flow concentrations. This is also due to the time-of-travel of the volatile chlorobenzene. The extra travel-time of 15.0 days versus 4.1 days allows for a great deal of decay to occur.

Referring back to Figure 6, one can see there is an industrial discharge at RM 332.2, between Ironton and Greenup. There is a discharge of chlorobenzene at this point and due to its proximity to the Greenup and Ironton intakes, little decay occurs. Figures 7 and 8 demonstrate there is not a smooth curve describing concentrations of pollutants as they travel downstream and how time-of-travel and decay rates can alter the vulnerability of communities. Figure 7 displays Chlorobenzene concentrations at the various flow scenarios. Figure 8 displays Nitrobenzene (less volatile) concentrations resulting from the same dischargers as Chlorobenzene at the same volumetric rates.

The concentrations themselves are not important since they are so low. The real importance lies in the interaction between flow and pollutant characteristics.

Chlorobenzene is highly volatile with a value of .55/day compared to nitrobenzene exhibiting a value of .05/day. In Figure 7, one can see how the low flow chlorobenzene concentrations fall far below the average and high flow levels. The speed at which the chlorobenze travels downstream at higher flows does not allow for much decay to occur. As the time-of-travel increases, so does the amount of decay, thus the low concentrations of pollutants downstream during low flow. Figure 8 reinforces this concept

TABLE 17

ORGANOLEPTIC POLLUTANT CONCENTRATIONS AT LOW FLOW

POLLUTANT	CRITERIA (ug/L)	DECAY RATE/day	CONCENTRATIONS AT UTILITIES IN ug/L							
			GALLI.	HUNT.	ASHL.	IRON.	GREE.	PORT.	MAYS.	CINTI AREA
Copper	1000.0	Cons.	2.190	2.200	4.040	5.430	5.750	5.330	5.240	4.740
Zinc	5000.0	Cons.	1.110	1.120	3.120	4.510	4.500	4.170	4.100	3.710
Chlorobenzene	20.0	.5500	.000	.00043	.00020	.00014#	.02470	.01135	.00164#	.00013#
Nitrobenzene	30.0	.0600	.000	.00088	.00070	.00067	.03061	.02621	.02073	.01425
Phenol	3000.0	.0250	.09791	.09208	.09206	.22826	.25712	.23055	.20689	.16686
2-Chlorophenol	.1	.0550	.000	.00088	.00071	.03068*	.03068*	.02645*	.02130*	.01498
2,4-Dichlorophenol	.3	.0100	.000	.00094	.00080	.03139*	.03130*	.02871	.02720	.02350
2,4,6-Trichlorophenol	2.0	.0250	.000	.00046	.00038	.01558	.01558	.01397	.01253	.01011
Pentachlorophenol	30.0	.0100	.02015	.01968	.01659	.02286	.02286	.02091	.01981	.01711
2,4-Dimethylphenol	400.0	.0600	.07138	.06166	.04910	.07733	.07733	.06621	.05238	.03601
Acenaphthene	20.0	.2000	.000	.00014	.00010	.00008	.00573	.00409	.00197	.00072

Cons. = No Volatilization

#Sensitive Consumers Affected

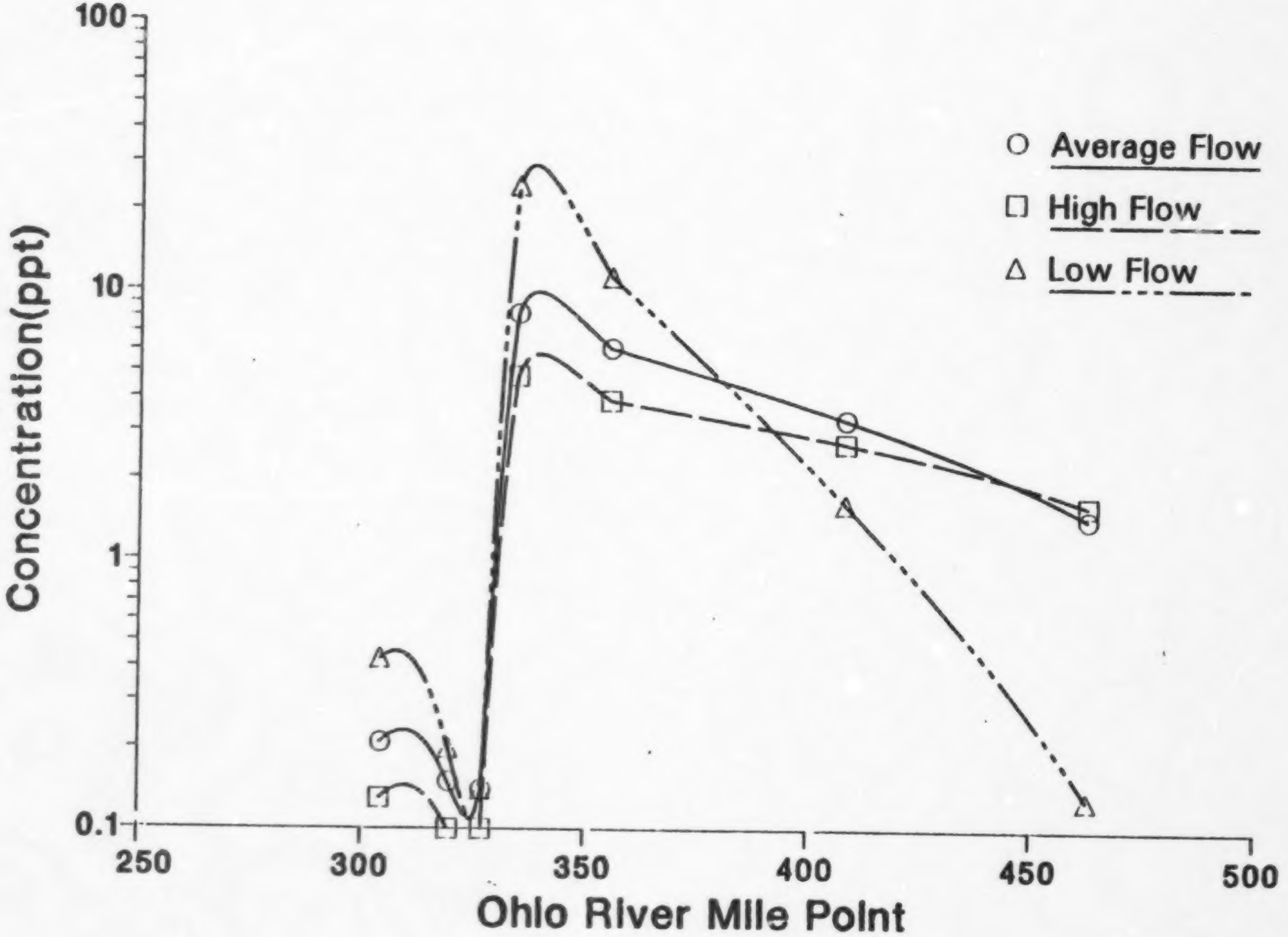

Figure 7. Chlorobenzene Concentrations at Various Flow Scenarios

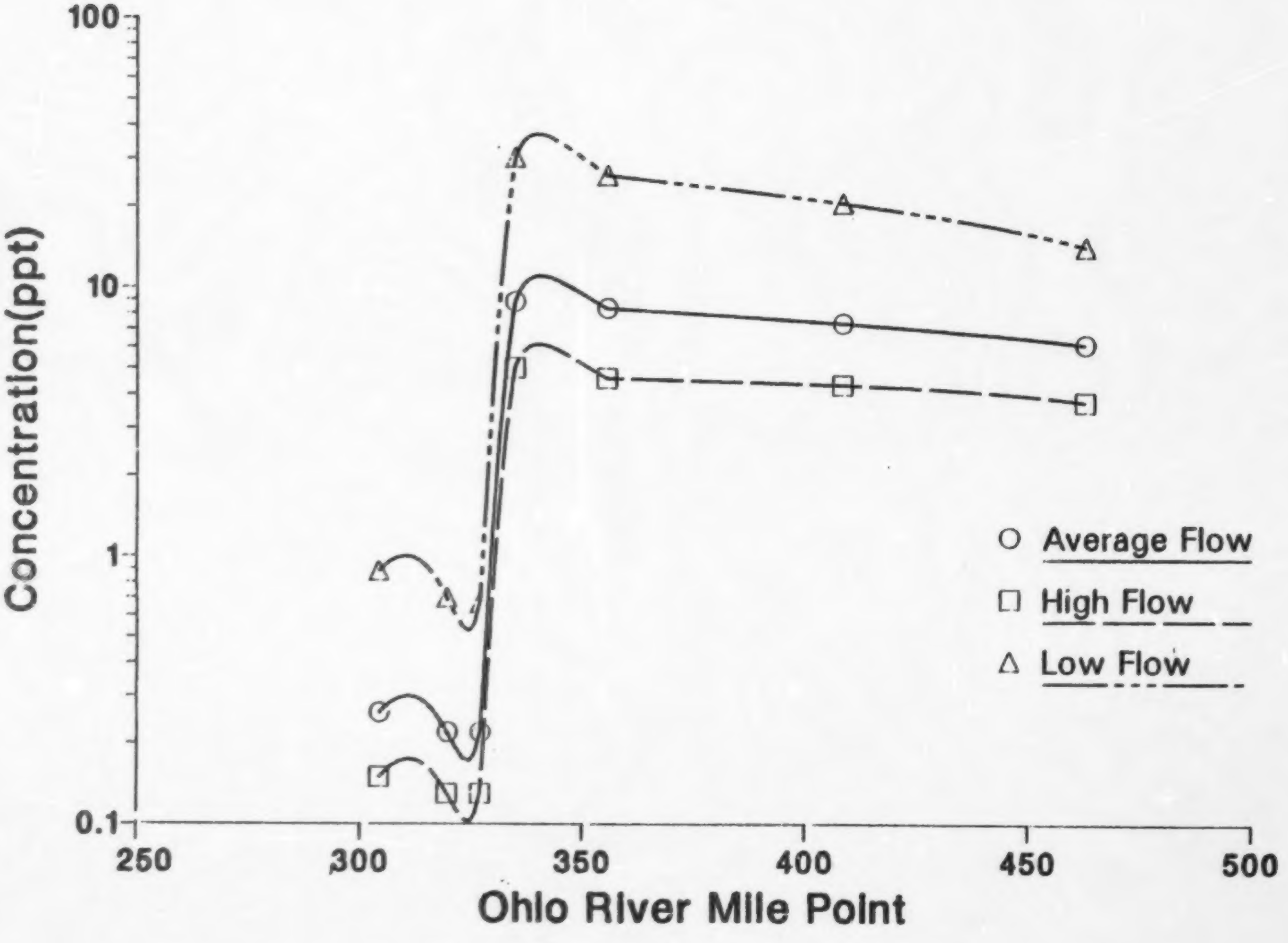

Figure 8. Nitrobenzene Concentrations at Various Flow Scenarios

due to the fact that there is no crossing over of the curves at various flow scenarios. Nitrobenzene's low volatility owes most of its decay to dilution, hence the almost parallel curves in Figure 8 exhibiting the expected relationships. One can see the low flow curve beginning to drop a bit more quickly than the high and average flow curves around the 450 mile point as the low decay rate begins to have an effect.

Industries and regulatory agencies should no longer assume that discharges can simply be allowed to increase during high flow and it may not be necessary to impose overly strict effluent guidelines for low flow situations. This becomes much more important when discussing the toxic and carcinogenic pollutants.

Also displayed in Table 17, are the concentrations for 2-Chlorophenol and 2,4-Dichlorophenol which exceed 10% of the Criteria at Ironton and Greenup. Portsmouth, Maysville and Cincinnati Area intakes have concentrations of 2-Chlorophenol exceeding the 10% Criteria also, but the 2,4-Dichlorophenol levels have dropped below the 10% level. Thus, it is possible that some of the consumers in the cities mentioned above would notice taste or odor problems with their drinking water or have the quality of food and beverages impaired.

Table 18 summarizes the pollutants that exceed the taste and odor guidelines. The 10% level represents those sensivitive consumers that could be affected and the 100% level accounts for the general population. One can see that only during low flow periods would the utilities have to be concerned about taste and odor problems from the priority pollutants. Although taste and odor problems are not dangerous, they probably create greater public response than do reports of possible carcinogens. Historically, aesthetic considerations have often been the basis for regulation rather than public health.

TABLE 18

SUMMARY OF ORGANOLEPTIC POLLUTANTS EXCEEDING GUIDELINES

Utility	Average Flow		High Flow		Low Flow	
	10% Level	100% Level	10% Level	100% Level	10% Level	100% Level
Gallipolis	None	None	None	None	None	None
Huntington	None	None	None	None	None	None
Ashland	None	None	None	None	None	None
Ironton	None	None	None	None	2-Chlorophenol 2,4-Dichlorophenol	None
Greenup	None	None	None	None	2-Chlorophenol 2,4-Dichloropnehol	None
Portsmouth	None	None	None	None	2-Chlorophenol	None
Maysville	None	None	None	None	2-Chlorophenol	None
Cincinnati Area	None	None	None	None	2-Chlorophenol	None

Simulations of Toxic Pollutants

Table 19 displays the concentrations of the 26 toxic pollutants for each utility in the case study area at average flow. As can be seen, Inorganic mercury and cadmium exceed 10% of the Criteria at Ironton, Greenup, Portsmouth, Maysville and Cincinnati Area utilities thus possibly subjecting the more sensitive consumers to physical distress.

Ingestion of cadmium results in gastro-intestinal type of poisoning resembling food poisoning in its symptoms of sudden nausea, salivation, vomiting and diarrhea and abdominal pain and discomfort. Mercury, after absorbtion circulates in the blood and is stored in the liver, kidneys, liver, spleen and bone. After sometime, systemic poisoning can occur in one of the organs causing physiological disturbances to that organ (Sax, 1975).

A person, for instance, with poorly functioning kidneys could be highly susceptible to concentrations demonstrated in Table 19, whereas a healthy person may be able to eliminate the mercury through normal means such as urine, sweat, salive, etc. and not be affected.

One can clearly see the evidence of the various potencies of the toxic pollutants in this table. For example, cadmium and chromium have identical concentrations throughout the case study area at each utility. However, cadmium is more toxic as reflected by the Drinking Water Standards in Column 2, thus possibly affecting people sooner than chromium might although having the same concentrations.

Table 20 exhibits the high flow concentrations for toxic pollutants simulated by QUAL-II. Once again, mercury exceeds 10% of the Criteria despite the greater dilution during high flows. Cadmium levels were reduced below the 10% level. Both mercury and cadmium are "Conservative Constituents" experiencing no volatilization.

TABLE 19

TOXIC POLLUTANT CONCENTRATIONS AT AVERAGE FLOW

POLLUTANT	CRITERIA (ug/L)	DECAY RATE/day	CONCENTRATIONS AT UTILITIES IN ug/L GALLI.	HUNT.	ASHL.	IRON.	GREE.	PORT.	MAYS.	CINC. AREA
Acrolein	325	.1000	.000	.00052	.00043	.00042	.01769	.01573	.01387	.01093
α-Endosulfan	74	.0550	.000	.00001	.000	.000	.00018	.00016	.00015	.00013
Endrin	1@	.0010	.000	.00001	.000	.000	.00018	.00017	.00016	.00015
Antimony	146	Cons.	.310	.320	.840	.920	1.010	.930	.910	.830
Cadmium	10@	Cons.	.310	.320	.890	1.280*	1.380*	1.280*	1.250*	.130*
Chromium	50@	Cons.	.310	.320	.890	1.280	1.380	1.280	1.250	1.130
Cyanide	3770	Cons.	.580	.590	1.740	2.380	2.560	2.370	2.330	2.100
Lead	50@	Cons.	.310	.320	.890	1.280	1.380	1.280	1.250	1.130
Mercury	.1440	Cons.	.00247	.00272	.0061	.04643*	.05571*	.05163*	.05070*	.04579*
Nickel	632	Cons.	.020	.03000	.0700	.460	.550	.510	.500	.450
Selenium	10@	Cons.	.00247	.00272	.00232	.00980	.01855	.01717	.01686	.01523
Silver	50@	Cons.	.03138	.03189	.08887	.12842	.13715	.12697	.12468	.11261
Thallium	13	Cons.	.03138	.03162	.08415	.09156	.09154	.08475	.08322	.07517
1,1,1-Trichloroethane	18400	.5200	.000	.00043	.00031	.00028	.01625	.01253	.00706	.00316
1,3-Dichloropropene	87	.5300	.000	.00043	.00031	.00028	.01663	.01247	.00695	.00307
1,3-Dichlorobenzene	400	.5500	.000	.00021	.00015	.00014	.00829	.00617	.00337	.00145
1,4-Dichlorobenzene	400	.5500	.000	.00011	.00008	.00007	.00415	.00308	.00168	.00072
Bis(2-chloroisopropyl)ether	34.7	.3800	.000	.00046	.00034	.00032	.01698	.01351	.00883	.00477
Ethylbenzene	710	.6100	.00926	.00600	.00855	.03786	.04261	.03096	.01746	.00631
Toluene	14300	.6500	.00057	.00057	.00474	.04114	.04525	.03236	.01591	.00599
2,4-Dinitrophenol	70	.000001	.000	.00014	.00012	.00012	.00449	.00416	.00408	.00369
4,6-Dinitro-o-cresol	13.4	.0700	.000	.00013	.00011	.00011	.00444	.00400	.00364	00299
Dimethyl Pthalate	313000	.0070	.000	.00014	.00012	.00012	.00449	.00414	.00404	.00361
Diethyl Pthalate	350000	.0050	.01638	.01633	.01392	.01763	.02198	.02031	.01984	.01779
Dibutyl Pthalate	34000	.0250	.01572	.01544	.01531	.03498	.03918	.03590	.03432	.02996
Fluoranthene	42	.0350	.000	.00043	.00005	.00004	.00179	.00163	.00061	.00307

Cons. = No Volatilization   * Sensitive Consumers Affected   @ Existing Standard

TABLE 20

TOXIC POLLUTANT CONCENTRATIONS AT HIGH FLOW

POLLUTANT	CRITERIA (ug/L)	DECAY RATE/day	CONCENTRATIONS AT UTILITIES IN ug/L							
			GALLI.	HUNT.	ASHL.	IRON.	GREE.	PORT.	MAYS.	CINC. AREA
Acrolein	325	.1000	.000	.00030	.00025	.00025	.01005	.00909	.00876	.00701
α-Endosulfan	74	.0550	.000	.000	.000	.000	.00010	.00009	.00009	.00008
Endrin	1@	.0010	.000	.000	.000	.000	.00010	.00009	.00009	.00008
Antimony	146	Cons.	.180	.180	.480	.520	.570	.530	.520	.470
Cadmium	10@	Cons.	.180	.180	.500	.720	.780	.720	.710	.640
Chromium	50@	Cons.	.180	.180	.500	.720	.780	.720	.710	.640
Cyanide	3770	Cons.	.330	.330	.980	1.340	1.450	1.340	1.320	1.190
Lead	50@	Cons.	.180	.180	.500	.720	.780	.720	.710	.640
Mercury	.1440	Cons.	.00139	.00153	.00385	.02621*	.03148*	.02916*	.02864*	.02588
Nickel	632	Cons.	.010	.020	.040	.260	.310	.290	.280	.260
Selenium	10@	Cons.	.00139	.00153	.00131	.00553	.01047	.00970	.00952	.00861
Silver	50@	Cons.	.01767	.01796	.05015	.07249	.07742	.07170	.07042	.06365
Thallium	13	Cons.	.01767	.01781	.04748	.05168	.05167	.04786	.04701	.04248
1,1,1-Trichloroehtane	18400	.5200	.000	.00027	.00021	.00019	.00970	.00796	.00567	.00341
1,3-Dichloropropene	87	.5300	.000	.00027	.00021	.00019	.00969	.00793	.00561	.00335
1,3-Dichlorobenzene	400	.5500	.000	.00013	.00010	.00010	.00484	.00394	.00275	.00162
1,4-Dichlorobenzene	400	.5500	.000	.00007	.00005	.00005	.00242	.00197	.00138	.00081
Bis(2-chloroisopropyl)ether	34.7	.3800	.000	.00028	.00022	.00021	.00981	.00832	.00645	.00433
Ethylbenzene	710	.6100	.00879	.00681	.00767	.02469	.02823	.02269	.01528	.00859
Toluene	14300	.6500	.00061	.00059	.00293	.02422	.02768	.02204	.01449	.00789
2,4-Dinitrophenol	70	.000001	.000	.00008	.00007	.00007	.00253	.00235	.00231	.00208
4,6-Dinitro-o-cresol	13.4	.0700	.000	.00008	.00006	.00006	.00252	.00230	.00216	.00185
Dimethyl Pthalate	313000	.0070	.000	.00008	.00007	.00007	.00253	.00234	.00229	.00206
Diethyl Pthalate	350000	.0050	.00927	.00926	.00791	.01001	.01247	.01157	.01130	.01017
Dibutyl Pthalate	34000	.0250	.00906	.00897	.00890	.02004	.02245	.02067	.01998	.01771
Fluoranthene	42	.0350	.000	.00003	.00003	.00003	.00101	.00093	.00089	.00029

Cons. = No Volatilization * Sensitive Consumers Affected @ Existing Standard

It seems that all pollutants with decay rates greater than .46/day will exhibit higher concentrations at the high flow scenario of 220,000 cfs than at average or low flows. For the low flow scenario of 35,000 cfs, those pollutants with a decay rate greater than .38/day will exhibit lower concentrations than at average or high flows. There are probably tradeoffs between flows and decay rates where either parameter takes precedent.

Table 21 lists the low flow concentrations for the toxic pollutants. Based on Tables 19 and 20 one would expect cadmium and mercury to exceed the 10% level and even approach the value where the general population would be affected. This holds true since these are conservative constituents and do not experience volatilization during the slow journey downstream during low flow.

Cadmium exceeds the 10% level at every utility during low flow periods. Mercury exeeds the 10% level at Ashland, but even more significantly, actually exceeds the Water Quality Criteria for the general population at Ironton, and for the remainder of the case study area. The peak concentration of mercury occurs at Greenup, reflecting the proximity of E. I. DuPont de Nemours, outfall just 2.5 miles upstream of Greenup's intake.

Concentrations of chromium and lead exceed the 10% level at Greenup also. Chromium ingestion can result in ulcers to mucous membranes,

TABLE 21

TOXIC POLLUTANT CONCENTRATIONS AT LOW FLOW

POLLUTANT	CRITERIA (ug/L)	DECAY RATE/day	CONCENTRATIONS AT UTILITIES IN ug/L GALLI.	HUNT.	ASHL.	IRON.	GREE.	PORT.	MAYS.	CINC. AREA
Acrolein	325	.1000	.000	.00165	.00126	.00117	.06003	.04877	.03343	.01918
αEndosulfan	74	.0550	.000	.00002	.00001	.00001	.00061	.00053	.00043	.00030
Endrin	1@	.0010	.000	.00002	.00002	.00002	.00063	.00058	.00057	.00051
Antimony	146	Cons.	1.11	1.12	2.97	3.23	3.53	3.27	3.22	2.91
Cadmium	10@	Cons.	1.11*	1.12*	3.13*	4.51*	4.84*	4.49*	4.41*	3.99
Chromium	50@	Cons.	1.11	1.12	3.13	4.51	5.00*	4.49	4.41	3.99
Cyanide	3770	Cons.	2.04	2.08	6.11	8.36	9.01	8.35	8.20	7.42
Lead	50@	Cons.	1.11	1.12	3.13	4.51	5.00*	4.49	4.41	3.99
Mercury	.1440	Cons.	.00870	.00959	.024*	.16322	.19596	.18163	.17841	.16138
Nickel	632	Cons.	.090	.100	.240	1.63	1.94	1.80	1.76	1.60
Selenium	10@	Cons.	.00870	.00959	.00818	.03445	.06517	.06040	.05933	.05367
Silver	50@	Cons.	.11066	.11249	.31305	.45146	.48190	.44666	.43875	.39686
Thallium	13	Cons.	.11066	.11153	.29641	.33188	.32166	.29814	.29286	.26490
1,1,1-Trichloroethane	18400	.5200	.000	.00089	.00043	.00031	.05000	.02384	.00381	.00035
1,3-Dichloropropene	87	.5300	.000	.00088	.00042	.00030	.04980	.02346	.00362	.00032
1,3-Dichlorobenzene	400	.5500	.000	.00043	.00020	.00014	.02470	.01135	.00164	.00013
1,4-Dichlorobenzene	400	.5500	.000	.00021	.00010	.00007	.01235	.00568	.00082	.00007
Bis(2-chloroisopropyl)ether	34.7	.3800	.000	.00109	.00061	.00047	.05295	.03005	.00773	.00129
Ethylbenzene	710	.6100	.00259	.00097	.01489	.10274	.09782	.04177	.00494	.00031
Toluene	14300	.6500	.00008	.00039	.00018	.12035	.10795	.04391	.00454	.00025
2,4-Dinitrophenol	70	.000001	.000	.00048	.00041	.00041	.01578	.01462	.01436	.01299
4,6-Dinitro-o-cresol	13.4	.0700	.000	.00043	.00034	.00032	.01523	.01287	.00982	.00645
Dimethyl Pthalate	313000	.0070	.000	.00047	.00040	.00040	.01572	.01444	.01383	.01211
Diethyl Pthalate	350000	.0050	.05635	.05569	.04721	.06003	.07515	.06919	.06674	.05900
Dibutyl Pthalate	34000	.0250	.04896	.04604	.04603	.11413	.12751	.11434	.10260	.08275
Fluoranthene	42	.0350	.000	.00018	.00015	.00015	.00620	.00549	.00484	.00375

Cons. = No Volatilization   * Sensitive Consumers Affected   @ Existing Standard   All Consumers Affected although deep, are relatively painless. Lead is a cumulative poison. Increasing amounts build up in the body and eventually a point is reached where symptons and disability occur. Lead can eventually cause anemia which is rarely severe. Lead may also have a damaging effect on any organ or tissue it comes in contact with. Since low flow periods occur usually during a few months each year, normal adults may accumulate these toxics for a short time, but eliminate them during the rest of the year thus showing no ill effects. However, little is known about reported episodes of these pollutants and a long-term effect may result (Sax, 1975).

Table 22 summarizes the number of Water Quality Criteria values that are exeeded at the utilities. This in itself would not be sufficient to establish which utility is the most vulnerable. However, it does highlight the differences between utilities and flow scenarios.

Simulations of Carcinogenic Pollutants

The analysis of the carcinogenic pollutants proceeds in a different manner than the previous analyses for toxic and organoleptic pollutants. In assessing risks to carcinogens, there is no single value that signifies a health hazard exists for each pollutant. Rather, the Water Quality Criteria describes the carcinogenicity at the 1×10^{-5} risk level. Based on these values, the expected death rate per pollutant per year to a community can be calculated.

Table 23 lists the carcinogenic priority pollutants at average flow that had values at the Gallipolis intake. Column 1 lists the pollutant, column 2 lists the concentration assigned to the 10^{-5} risk level, column 3 lists the simulated concentration at the intake, column 4 describes the calculated risk level for that particular concentration and column 5 shows

TABLE 22

SUMMARY OF TOXIC POLLUTANTS EXCEEDING HEALTH GUIDELINES

	Average Flow		High Flow		Low Flow	
Utility	10% Level	100% Level	10% Level	100% Level	10% Level	100% Level
Gallipolis	None	None	None	None	Cadmium	None
Huntington	None	None	None	None	Cadmium	None
Ashland	None	None	None	None	Cadmium Mercury	None
Ironton	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury
Greenup	Cadmium Mercury	None	Mercury	None	Cadmium Lead Chromium	Mercury
Portsmouth	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury
Maysville	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury
Cincinnati Area	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury

the expected number of deaths attributable to that pollutant per year per 100,000 people. The only no risk level is "0" concentration, it is assumed that all carcinogens have some levels of risk.

TABLE 23

CARCINOGENIC RISK LEVELS FOR GALLIPOLIS, OHIO

(River Mile 268.5)

Pollutant	Carcinogenicity at the $1x10^{-5}$ risk level	Simulated Concentration	Risk Level	Expected deaths/year/ 100,000
Arsenic	22 ng/L	31.38 ng/L	$1.43x10^{-5}$	$2.04x10^{-2}$
PCB-1254	0.79	0.21	$2.66x10^{-6}$	$3.8x10^{-3}$
Dichloromethane	1900	22.15	$1.17x10^{-7}$	$2.0x10^{-4}$
Chloroform	1900	22.15	$1.17x10^{-7}$	$2.0x10^{-4}$
1,2-Dichloroethane	9400	20.34	$2.16x10^{-8}$	$3.1x10^{-5}$
TCE	2700	19.75	$7.31x10^{-9}$	$1.0x10^{-5}$
Tetrachloroethene	8000	9.88	$1.24x10^{-8}$	$1.8x10^{-5}$
Benzene	6600	10.36	$1.57x10^{-7}$	$2.0x10^{-4}$
		Total expected deaths/year/100,000 = .0249		

As demonstrated by this table the risk levels are very small, and even totaled they account for only 2.5 extra deaths per 10,000,000 people. Since Gallpolis is a city of only 11,000 people, the level of risk is extremely low, and any costly addition to their water treatment system would be unnecessary. Of course, this implicitly assigns a dollar value to human life, but this is necessary when allocating scarce resources.

The QUAL-II simulations assumed zero levels of pollutants at the beginning of the case study. To make a more realistic analysis, actual data from water samples taken above Gallipolis to set the background levels of pollutants entering the case study area would be necessary. However, this is far beyond the scope of this study.

Similar analyses are performed for the remaining utilities in the case study area. Variations in flow will be explored for carcinogens later. Tables 24 through 30 present the risk levels to the remaining utilities and the expected number of deaths from the pollutants.

As can be seen, the expected number of deaths increase until it peaks at Greenup, Kentucky then gradually decreases downstream. Nationally, the total cancer death rate is approximately 140/100,000 people. Gastrointestinal cancer accounts for about one-third of these, therefore one can begin to put into perspective the relative levels of risk each utility faces. Greenup, Kentucky is the most vulnerable to carcinogenic pollutants in the case study area. Greenup's close downstream location to the E.I. DuPont de Nemours outfall once again is a main factor as it was for the toxic and organoleptic pollutants. The majority of the risk for all the utilities lie in only a few pollutants. In Greenup's case, Bis(chloro methyl) ether accounts for 6.33 of the 6.47 expected deaths per 100,000. This highlights the usufullness of modeling the pollutants in addition to pinpointing the problem pollutants. Controlling one pollutant may solve the entire problem. Other important pollutants are Arsenic and Beryllium followed by Aldrin, Dieldrin, Heptachlor and the PCB's. To put into perspective the risk levels for each pollutant in Tables 24-30, one can compare the estimated life time risks of death for some other events displayed in Table 31 (Malcolm Pirnie, Inc., 1982).

TABLE 24

CARCINOGENIC RISK LEVELS FOR HUNTINGTON, W. VA.
(River Mile 304.3)

Pollutant	Carcinogencity of $1x10^{-5}$ risk level (ng/L)	Simulated Concentration (ng/L)	Risk Level	Expected Number o Deaths/100,000 per year
Aldrin	.74	.01	1.35×10^{-7}	1.93×10^{-4}
α-BHC	22	.03	1.36×10^{-8}	1.94×10^{-5}
β-BHC	134	.03	2.24×10^{-9}	3.20×10^{-6}
γ-BHC	186	.03	1.61×10^{-9}	2.30×10^{-6}
Dieldrin	.71	.01	1.41×10^{-7}	2.01×10^{-4}
Arsenic	22	31.89	1.45×10^{-5}	2.00×10^{-2}
Beryllium	68	.27	3.97×10^{-8}	5.67×10^{-5}
PCB-1232	.79	.01	1.27×10^{-7}	1.81×10^{-4}
PCB-1254	.79	.14	1.77×10^{-6}	2.53×10^{-3}
Chloromethane	1900	.41	2.16×10^{-9}	3.09×10^{-6}
Dichloromethane	1900	14.93	7.86×10^{-8}	1.12×10^{-4}
Chlorodibromomethane	1900	.45	2.37×10^{-9}	3.39×10^{-6}
Dichlorobromomethane	1900	.42	2.21×10^{-9}	3.16×10^{-6}
Tribromomethane	1900	.22	1.16×10^{-9}	1.66×10^{-6}
Chloroform	1900	14.93	7.86×10^{-8}	1.12×10^{-4}
Carbon Tetrachloride	4000	.20	5.00×10^{-10}	7.14×10^{-7}
Trichlorofluoromethane	1900	.42	2.21×10^{-9}	3.16×10^{-6}
Dichlorodifluormethane	1900	.40	2.11×10^{-9}	3.01×10^{-6}
1,2-Dichloroethane	9400	13.64	1.45×10^{-8}	2.07×10^{-5}
1,1,2-Trichloroethane	6000	.43	7.17×10^{-10}	1.02×10^{-6}
1,1,2,2-Tetrachloroethane	1700	.22	1.29×10^{-9}	1.84×10^{-6}
TCE	27000	12.78	4.73×10^{-9}	6.76×10^{-6}
Tetrachloroethene	8000	6.39	7.99×10^{-9}	1.14×10^{-5}
Hexachlorobutadiene	4470	.10	2.23×10^{-10}	3.19×10^{-7}
Bis(chloromethyl)ether	0.038	.44	1.16×10^{-4}	1.70×10^{-1}
Bis(2-Chloroethyl)ether	300	.53	1.77×10^{-8}	2.53×10^{-5}
Vinyl Chloride	2000	.54	2.70×10^{-10}	3.86×10^{-7}
Benzene	6000	7.00	1.06×10^{-8}	1.51×10^{-5}
2,4-Dinitroluene	1100	.27	2.45×10^{-9}	3.50×10^{-6}
Acenaphthylene	28	.04	1.43×10^{-8}	2.04×10^{-5}
Anthracene	28	.04	1.43×10^{-8}	2.04×10^{-5}
Benzo(a)anthracene	28	.01	3.57×10^{-9}	5.10×10^{-6}
Benzo(ghi)perylene	28	.01	3.57×10^{-9}	5.10×10^{-6}
Chrysene	28	.01	3.57×10^{-9}	5.10×10^{-6}
Fluorene	28	.04	1.43×10^{-8}	2.04×10^{-5}
Phenanthrane	28	.04	1.43×10^{-8}	2.04×10^{-5}
Acrylontrile	580	.02	4.00×10^{-10}	5.71×10^{-7}
Diphenylnitrosamine	49000	.02	4.08×10^{-12}	5.83×10^{-9}

TOTAL EXPECTED DEATHS = .1936

TABLE 25

CARCINOGENIC RISK LEVELS FOR ASHLAND, KENTUCKY

(River Mile 319.6)

Pollutant	Carcinogenicity of 1×10^{-5} risk level (ng/L)	Simulated Concentration (ng/L)	Risk Level	Expected Number of Deaths/100,000 per year
α-BHC	22	.02	9.09×10^{-9}	1.30×10^{-5}
β-BHC	134	.02	1.49×10^{-9}	2.13×10^{-6}
γ-BHC	186	.02	1.08×10^{-9}	1.54×10^{-6}
Arsenic	22	88.87	4.04×10^{-5}	6.00×10^{-2}
Berillium	68	4.72	6.94×10^{-7}	9.91×10^{-4}
PCB-1254	0.79	.10	1.27×10^{-6}	1.81×10^{-3}
Chloromethane	1900	.29	1.53×10^{-9}	2.21×10^{-6}
Dichloromethane	1900	10.59	5.57×10^{-8}	7.96×10^{-5}
Chlorodibromomethane	1900	.34	1.79×10^{-9}	2.56×10^{-6}
Dichlorobromomethane	1900	.30	1.58×10^{-9}	2.26×10^{-6}
Tribromomethane	1900	.16	8.42×10^{-10}	1.20×10^{-6}
Chloroform	1900	10.59	5.57×10^{-8}	7.96×10^{-5}
Carbon Tetrachloride	4000	.14	3.50×10^{-10}	5.00×10^{-7}
Trichlorofluoromethane	1900	.30	1.58×10^{-9}	2.26×10^{-6}
Dichlorodifluoromethane	1900	.28	1.47×10^{-9}	2.10×10^{-6}
1,2-Dichloroethane	9400	9.65	1.02×10^{-8}	1.54×10^{-5}
1,1,2-Trichloroethane	6000	.31	5.17×10^{-10}	7.39×10^{-7}
1,1,2,2-Tetrachloroethane	1700	.16	9.41×10^{-10}	1.34×10^{-6}
TCE	27000	8.89	3.29×10^{-9}	4.70×10^{-6}
Tetrachloroethene	8000	4.44	5.55×10^{-9}	7.93×10^{-6}
Hexachlorobutadiene	4470	.07	1.57×10^{-10}	2.24×10^{-7}
Bis(chloromethyl)ether	0.038	.33	8.68×10^{-5}	1.20×10^{-1}
Bis(2-chloroethyl)ether	300	.44	1.47×10^{-8}	2.10×10^{-5}
Vinyl Chloride	20000	.46	2.30×10^{-10}	3.29×10^{-7}
Benzene	6600	4.97	7.53×10^{-9}	1.08×10^{-5}
2,4-Dinitrotoluene	1100	.23	2.09×10^{-9}	2.99×10^{-6}
Acenaphthylene	28	.03	1.07×10^{-8}	1.53×10^{-5}
Anthracene	28	.03	1.07×10^{-8}	1.53×10^{-5}
Fluorene	28	.03	1.07×10^{-8}	1.53×10^{-5}
Phenanthrene	28	.03	1.07×10^{-8}	1.53×10^{-5}
Acrylonitrile	580	.02	3.45×10^{-10}	4.93×10^{-7}
Diphenylnitrosamine	49000	.02	4.08×10^{-12}	5.83×10^{-9}

TOTAL EXPECTED DEATHS = .1831

TABLE 26

CARCINOGENIC RISK LEVELS FOR IRONTON, OHIO

(River Mile 327.0)

Pollutant	Carcinogenicity of $1x10^{-5}$ risk level (ng/L)	Simulated Concentration (ng/L)	Risk Level	Expected Number of Deaths/100,00 per year
α-BHC	22	.02	9.09×10^{-9}	1.30×10^{-5}
β-BHC	134	.02	1.49×10^{-9}	2.13×10^{-6}
γ-BHC	186	.02	1.08×10^{-9}	1.54×10^{-6}
Arsenic	22	128.42	5.84×10^{-5}	8.00×10^{-2}
Beryllium	68	36.86	5.42×10^{-6}	1.00×10^{-2}
PCB-1254	0.79	.09	1.14×10^{-6}	1.63×10^{-3}
Chloromethane	1900	.25	1.32×10^{-9}	1.89×10^{-6}
Dichloromethane	1900	23.31	1.23×10^{-7}	1.76×10^{-4}
Chlorodibromomethane	1900	.31	1.63×10^{-9}	2.33×10^{-6}
Dichlorobromomethane	1900	.27	1.42×10^{-9}	2.03×10^{-6}
Tribromomethane	1900	.15	7.89×10^{-10}	1.13×10^{-6}
Chloroform	1900	23.31	1.23×10^{-7}	1.76×10^{-4}
Carbon Tetrachloride	4000	.12	3.00×10^{-10}	4.29×10^{-7}
Trichlorofluoromethane	1900	.26	1.37×10^{-9}	1.96×10^{-6}
Dichlorodifluoromethane	1900	.24	1.26×10^{-9}	1.80×10^{-6}
1,2-Dichloroethane	9400	8.64	9.19×10^{-9}	1.31×10^{-5}
1,1,2-Trichloroethane	6000	.28	4.67×10^{-10}	6.67×10^{-7}
1,1,2,2-Tetrachloroethane	1700	.14	8.24×10^{-10}	1.18×10^{-6}
TCE	27000	21.57	7.99×10^{-9}	1.14×10^{-5}
Tetrachloroethene	8000	10.78	1.34×10^{-8}	1.91×10^{-5}
Hexachlorobutadiene	4470	.06	1.34×10^{-10}	1.91×10^{-7}
Bis(chloromethyl)ether	0.038	.30	7.89×10^{-5}	1.10×10^{-1}
Bis(2-chloroethyl)ether	300	.44	1.47×10^{-8}	2.10×10^{-5}
Vinyl Chloride	20000	.46	2.30×10^{-10}	3.29×10^{-7}
Benzene	6600	4.46	6.75×10^{-9}	9.64×10^{-6}
2,4-Dinitrotoluene	1100	.23	2.09×10^{-9}	2.99×10^{-6}
Acenaphthylene	28	.03	1.07×10^{-8}	1.53×10^{-5}
Anthracene	28	.03	1.07×10^{-8}	1.53×10^{-5}
Fluorene	28	.03	1.07×10^{-8}	1.53×10^{-5}
Phenanthrene	28	.03	1.07×10^{-8}	1.53×10^{-5}
Acrylonitrile	580	.02	3.45×10^{-10}	4.93×10^{-7}
Diphenylnitrosamine	49000	.01	2.04×10^{-12}	2.91×10^{-9}

TOTAL EXPECTED DEATHS = .2022

TABLE 27

CARCINOGENIC RISK LEVELS FOR GREENUP, KENTUCKY

(River Mile 334.7)

Pollutant	Carcinogenicity of 1×10^{-5} risk level (ng/L)	Simulated Concentration (ng/L)	Risk Level	Expected Number of Deaths/100,000 per year
Aldrin	0.74	.18	2.43×10^{-6}	3.47×10^{-3}
α-BHC	22	.90	4.09×10^{-7}	5.84×10^{-4}
β-BHC	134	.90	6.72×10^{-8}	9.60×10^{-5}
γ-BHC	186	.89	4.78×10^{-8}	6.83×10^{-5}
Dieldrin	0.71	.18	7.08×10^{-6}	3.63×10^{-3}
DDE	0.24	.17	2.54×10^{-6}	1.01×10^{-2}
Heptachlor	2	.17	8.50×10^{-7}	1.21×10^{-3}
Arsenic	22	137.75	6.26×10^{-5}	9.00×10^{-2}
Beryllium	68	45.60	6.62×10^{-6}	1.00×10^{-2}
PCB-1221	0.79	.17	2.15×10^{-6}	3.07×10^{-3}
PCB-1232	0.79	.18	2.28×10^{-6}	3.26×10^{-3}
PCB-1242	0.79	.17	2.15×10^{-6}	3.07×10^{-3}
PCB-1248	0.79	.17	2.15×10^{-6}	3.07×10^{-3}
PCB-1254	0.79	.08	1.01×10^{-6}	1.44×10^{-3}
Chloromethane	1900	16.45	8.66×10^{-8}	1.24×10^{-4}
Dichloromethane	1900	37.45	1.97×10^{-7}	2.81×10^{-4}
Chlorodibromomethane	1900	16.93	8.91×10^{-8}	1.27×10^{-4}
Dichlorobromomethane	1900	16.58	8.73×10^{-8}	1.25×10^{-4}
Tribromomethane	1900	8.40	4.42×10^{-8}	6.31×10^{-5}
Chloroform	1900	38.60	2.07×10^{-7}	2.96×10^{-4}
Carbon Tetrachloride	4000	8.20	2.05×10^{-8}	2.93×10^{-5}
Trichlorofluoromethane	1900	16.54	8.71×10^{-8}	1.24×10^{-4}
Dichlorodifluoromethane	1900	16.34	8.60×10^{-8}	1.23×10^{-4}
1,2-Dichloroethane	9400	24.13	2.57×10^{-8}	3.67×10^{-5}
1,1,2-Trichloroethane	6000	16.70	2.78×10^{-8}	3.97×10^{-5}
1,1,2,2-Tetrachloroethane	1700	8.36	4.92×10^{-8}	7.03×10^{-5}
TCE	27000	35.55	1.32×10^{-8}	1.89×10^{-5}
Tetrachloroethene	8000	18.35	2.29×10^{-8}	3.27×10^{-5}
Hexachlorobutadiene	4470	4.08	9.13×10^{-9}	1.30×10^{-5}
Bis(chloromethyl)ether	0.038	16.82	4.43×10^{-3}	6.33
Bis(2-chloroethyl)ether	300	17.80	5.93×10^{-7}	8.47×10^{-4}
Vinyl Chloride	20000	17.96	8.98×10^{-9}	1.28×10^{-5}
Benzene	6600	12.78	1.94×10^{-8}	2.77×10^{-5}
2,4-Dinitrotoluene	1100	8.95	8.12×10^{-8}	1.16×10^{-4}
Acenaphthylene	28	1.66	5.93×10^{-7}	8.47×10^{-4}
Anthracene	28	1.67	5.96×10^{-7}	8.51×10^{-4}
Benzo(a)anthracene	28	.18	6.43×10^{-8}	9.19×10^{-5}
Benzo(ghi)perylene	28	.18	6.43×10^{-8}	9.19×10^{-5}
Chrysene	28	.18	6.43×10^{-8}	9.19×10^{-5}
Fluorene	28	1.64	5.86×10^{-7}	8.37×10^{-4}
Phenanthrene	28	1.68	6.00×10^{-7}	8.57×10^{-4}
Pyrene	28	.18	6.43×10^{-8}	9.19×10^{-5}
Acrylonitrile	580	.87	1.50×10^{-8}	2.14×10^{-5}
Diphenylnitrosamine	49000	.83	1.69×10^{-10}	2.42×10^{-7}

TOTAL EXPECTED DEATHS = 6.4694

TABLE 28

CARCINOGENIC RISK LEVELS FOR PORTSMOUTH, OHIO

(River Mile 355.5)

Pollutant	Carcinogenicity of 1x10^{-5} risk level (ng/L)	Simulated Concentration (ng/L)	Risk Level	Expected Number of Deaths/100,000 per year
Aldrin	0.74	0.16	2.16×10^{-6}	3.09×10^{-3}
α-BHC	22	0.82	3.73×10^{-7}	5.33×10^{-4}
β-BHC	134	0.83	6.19×10^{-8}	8.84×10^{-5}
γ-BHC	186	0.82	4.41×10^{-8}	6.30×10^{-5}
Dieldrin	0.71	0.17	2.39×10^{-6}	3.41×10^{-3}
DDE	0.24	0.14	5.83×10^{-6}	8.33×10^{-3}
Heptachlor	2.0	0.13	6.50×10^{-7}	9.29×10^{-4}
Arsenic	22.0	127.52	5.80×10^{-5}	8.0×10^{-2}
Beryllium	68	42.22	6.21×10^{-6}	9.0×10^{-3}
PCB-1221	0.79	0.14	1.77×10^{-6}	2.53×10^{-3}
PCB-1232	0.79	0.16	2.03×10^{-6}	2.90×10^{-3}
PCB-1242	0.79	0.12	1.52×10^{-6}	2.17×10^{-3}
PCB-1248	0.79	0.12	1.52×10^{-6}	2.17×10^{-3}
PCB-1254	0.79	0.06	7.59×10^{-7}	1.08×10^{-3}
Chloromethane	1900	11.95	6.29×10^{-8}	8.99×10^{-5}
Dichloromethane	1900	27.85	1.47×10^{-7}	2.10×10^{-4}
Chlorodibromomethane	1900	13.36	7.03×10^{-8}	1.0×10^{-4}
Dichlorobromomethane	1900	12.33	6.49×10^{-8}	9.27×10^{-5}
Tribromomethane	1900	6.47	3.41×10^{-8}	4.87×10^{-5}
Chloroform	1900	28.71	1.51×10^{-7}	2.16×10^{-4}
Carbon Tetrachloride	4000	5.91	1.48×10^{-8}	2.11×10^{-5}
Trichlorofluoromethane	1900	12.20	6.42×10^{-8}	9.17×10^{-5}
Dichlorodifluoromethane	1900	11.64	6.13×10^{-8}	8.72×10^{-5}
1,2-Dichloroethane	9400	17.88	1.90×10^{-8}	2.71×10^{-5}
1,1,2-Trichloroethane	6000	12.67	2.11×10^{-8}	3.01×10^{-5}
1,1,2,2-Tetrachloroethane	1700	6.37	3.75×10^{-8}	5.36×10^{-5}
TCE	27000	25.82	9.56×10^{-9}	1.37×10^{-5}
Tetrachloroethene	8000	13.33	1.67×10^{-8}	2.39×10^{-5}
Hexachlorobutadiene	4470	2.91	6.51×10^{-9}	9.30×10^{-6}
Bis(chloromethyl)ether	0.038	13.01	3.42×10^{-3}	4.89
Bis(2-chloroethyl)ether	300	16.08	5.36×10^{-7}	7.66×10^{-4}
Vinyl Chloride	20000	16.62	8.31×10^{-9}	1.19×10^{-5}
Benzene	6600	9.51	1.44×10^{-8}	2.06×10^{-5}
2,4-Dinitrotoluene	1100	8.22	7.47×10^{-8}	1.07×10^{-5}
Acenaphthylene	28	1.25	4.46×10^{-7}	6.37×10^{-4}
Anthracene	28	1.27	4.54×10^{-7}	6.49×10^{-4}
Benzo(a)anthracene	28	0.17	6.07×10^{-8}	8.67×10^{-5}
Benzo(ghi)perylene	28	0.17	6.07×10^{-8}	8.67×10^{-5}
Chrysene	28	0.17	6.07×10^{-8}	8.67×10^{-5}
Fluorene	28	1.19	4.25×10^{-7}	6.07×10^{-4}
Phenanthrene	28	1.30	4.64×10^{-7}	6.63×10^{-4}
Pyrene	28	0.16	5.71×10^{-8}	8.16×10^{-5}
Acrylonitrile	580	0.72	1.24×10^{-8}	1.77×10^{-5}
Diphenylnitrosamine	49000	0.62	1.27×10^{-10}	1.81×10^{-7}

TOTAL EXPECTED DEATHS = 5.0110

TABLE 29

CARCINOGENIC RISK LEVELS FOR MAYSVILLE, KENTUCKY

(River Mile 408.4)

Pollutant	Carcinogenicity of 1×10^{-5} risk level (ng/L)	Simulated Concentration (ng/L)	Risk Level	Expected Number of Deaths/100,000 per year
Aldrin	0.74	0.15	2.03×10^{-6}	2.9×10^{-3}
α-BHC	22	0.79	3.59×10^{-7}	5.13×10^{-4}
β-BHC	134	0.82	6.12×10^{-8}	8.74×10^{-5}
γ-BHC	186	0.78	4.19×10^{-8}	5.99×10^{-5}
Dieldrin	0.71	0.16	2.25×10^{-6}	3.21×10^{-3}
DDE	0.24	0.09	3.75×10^{-6}	5.40×10^{-3}
Heptachlor	2	0.08	4.00×10^{-7}	5.71×10^{-4}
Arsenic	22	125.23	5.69×10^{-5}	8.13×10^{-2}
Beryllium	68	41.46	6.10×10^{-6}	8.7×10^{-3}
PCB-1221	0.79	0.09	1.14×10^{-6}	1.63×10^{-3}
PCB-1232	0.79	0.15	1.90×10^{-6}	2.71×10^{-3}
PCB-1242	0.79	0.07	8.86×10^{-7}	1.27×10^{-3}
PCB-1248	0.79	0.07	8.86×10^{-7}	1.27×10^{-3}
PCB-1254	0.79	0.03	3.80×10^{-7}	5.43×10^{-4}
Chloromethane	1900	6.74	3.55×10^{-8}	5.07×10^{-5}
Dichloromethane	1900	15.21	8.01×10^{-8}	1.14×10^{-4}
Chlorodibromomethane	1900	8.55	4.50×10^{-8}	6.43×10^{-5}
Dichlorobromomethane	1900	6.74	3.55×10^{-8}	5.07×10^{-5}
Tribromomethane	1900	3.89	2.05×10^{-8}	2.93×10^{-5}
Chloroform	1900	15.68	8.25×10^{-8}	1.18×10^{-4}
Carbon Tetrachloride	4000	2.97	7.43×10^{-8}	1.06×10^{-5}
Trichlorofluoromethane	1900	6.53	3.44×10^{-8}	4.91×10^{-5}
Dichlorodifluoromethane	1900	5.64	2.97×10^{-8}	4.24×10^{-5}
1,2-Dichloroethane	9400	9.66	1.03×10^{-8}	1.47×10^{-5}
1,1,2-Trichloroethane	6000	7.29	1.22×10^{-8}	1.74×10^{-5}
1,1,2,2-Tetrachloroethane	1700	3.70	2.18×10^{-8}	3.11×10^{-5}
TCE	27000	13.24	4.90×10^{-9}	7.0×10^{-6}
Tetrachloroethene	8000	6.83	8.54×10^{-9}	1.22×10^{-5}
Hexachlorobutadiene	4470	1.42	3.18×10^{-9}	4.54×10^{-6}
Bis(chloromethyl)ether	0.038	7.90	2.08×10^{-3}	2.9714
Bis(2-chloroethyl)ether	300	14.80	4.93×10^{-7}	7.04×10^{-4}
Vinyl Chloride	20000	16.31	8.16×10^{-9}	1.17×10^{-5}
Benzene	6600	5.19	7.86×10^{-9}	1.12×10^{-5}
2,4-Dinitrotoluene	1100	7.90	7.18×10^{-8}	1.03×10^{-4}
Acenaphthylene	28	0.70	2.50×10^{-7}	3.57×10^{-4}
Anthracene	28	0.73	2.61×10^{-7}	3.73×10^{-4}
Benzo(a)anthracene	28	0.16	5.71×10^{-8}	8.16×10^{-5}
Benzo(ghi)perylene	28	0.16	5.71×10^{-8}	8.16×10^{-5}
Chrysene	28	0.16	5.71×10^{-8}	8.16×10^{-5}
Fluorene	28	0.61	2.18×10^{-7}	3.11×10^{-4}
Phenanthrene	28	0.79	2.82×10^{-7}	4.03×10^{-4}
Pyrene	28	0.16	5.71×10^{-8}	8.16×10^{-5}
Acrylonitrile	580	0.54	9.31×10^{-9}	1.33×10^{-5}
Diphenylnitrosamire	49000	.34	6.94×10^{-9}	9.91×10^{-8}

TOTAL EXPECTED DEATHS = 2.9882

TABLE 30

CARCINOGENIC RISK LEVELS FOR CINCINNATI AREA INTAKES

(River Mile 462.8)

Pollutant	Carcinogenicity of 1×10^{-5} risk level (ng/L)	Simulated Concentration (ng/L)	Risk Level	Expected Number of Deaths/100,000 per year
Aldrin	0.74	0.13	1.76×10^{-6}	2.51×10^{-3}
α-BHC	22	0.69	3.14×10^{-7}	4.49×10^{-4}
β-BHC	134	0.74	5.52×10^{-8}	7.79×10^{-5}
γ-BHC	186	0.68	3.66×10^{-8}	5.23×10^{-5}
Dieldrin	0.71	0.15	2.11×10^{-6}	3.01×10^{-3}
DDE	0.24	0.05	2.083×10^{-6}	2.96×10^{-3}
Heptachlor	2	0.04	2.00×10^{-7}	2.86×10^{-4}
Arsenic	22	113.10	5.14×10^{-5}	7.34×10^{-2}
Beryllium	68	37.44	5.51×10^{-6}	7.90×10^{-3}
PCB-1221	0.79	0.05	6.33×10^{-7}	9.04×10^{-4}
PCB-1232	0.79	0.13	1.65×10^{-6}	2.36×10^{-3}
PCB-1242	0.79	0.03	3.80×10^{-7}	5.43×10^{-4}
PCB-1248	0.79	0.03	3.80×10^{-7}	5.43×10^{-4}
PCB-1254	0.79	0.01	1.27×10^{-7}	1.81×10^{-4}
Chloromethane	1900	2.43	1.28×10^{-8}	1.83×10^{-5}
Dichloromethane	1900	6.54	3.44×10^{-8}	4.91×10^{-5}
Chlorodibromomethane	1900	4.49	2.36×10^{-8}	3.37×10^{-5}
Dichlorobromomethane	1900	2.90	1.53×10^{-8}	2.19×10^{-5}
Tribromomethane	1900	1.88	9.89×10^{-9}	1.41×10^{-5}
Chloroform	1900	6.75	3.55×10^{-8}	5.07×10^{-5}
Carbon Tetrachloride	4000	1.15	2.88×10^{-9}	4.11×10^{-6}
Trichlorofluoromethane	1900	2.73	1.44×10^{-8}	2.06×10^{-5}
Dichlorodifluoromethane	1900	2.11	1.11×10^{-8}	1.59×10^{-5}
1,2-Dichloroethane	9400	4.10	4.36×10^{-9}	6.23×10^{-6}
1,1,2-Trichloroethane	6000	3.35	5.58×10^{-9}	7.97×10^{-6}
1,1,2,2-Tetrachloroethane	1700	1.73	1.02×10^{-8}	1.46×10^{-5}
TCE	27000	5.26	1.95×10^{-9}	2.79×10^{-6}
Tetrachloroethene	8000	2.72	3.40×10^{-9}	4.68×10^{-6}
Hexachlorobutadiene	4470	0.53	1.19×10^{-9}	1.7×10^{-6}
Bis(chloromethyl)ether	0.038	3.88	1.02×10^{-3}	1.46×10
Bis(2-chloroethyl)ether	300	12.32	4.11×10^{-7}	5.87×10^{-4}
Vinyl Chloride	20000	14.73	7.37×10^{-9}	1.05×10^{-5}
Benzene	6600	2.23	3.38×10^{-9}	4.83×10^{-6}
2,4-Dinitrotoluene	1100	6.94	6.31×10^{-8}	9.01×10^{-5}
Acenaphthylene	28	0.31	1.11×10^{-7}	1.59×10^{-4}
Anthracene	28	0.34	1.21×10^{-7}	1.71×10^{-4}
Benzo(a)anthracene	28	0.15	5.36×10^{-8}	7.66×10^{-5}
Benzo(ghi)perylene	28	0.15	5.36×10^{-8}	7.66×10^{-5}
Chrysene	28	0.15	5.36×10^{-8}	7.66×10^{-5}
Fluorene	28	0.24	8.57×10^{-8}	1.22×10^{-4}
Phenanthrene	28	0.39	1.39×10^{-7}	1.99×10^{-4}
Pyrene	28	0.13	4.64×10^{-8}	6.63×10^{-5}
Acrylonitrile	580	0.35	6.48×10^{-9}	9.26×10^{-6}
Diphenylnitrosamine	49000	0.14	2.86×10^{-11}	4.09×10^{-8}

TOTAL EXPECTED DEATHS = 1.5571

TABLE 31

ESTIMATED LIFE TIME RISK OF DEATH

1 in a million or 1 x 10^{-6}	1 in one hundred thousand or 1 x 10^{-5}	1 in ten thousand or 1 x 10^{-4}
DIPTHERIA	GAS GANGRENE	ELECTROCUTION
ACUTE POLIO	HEMOPHILIA	FALL OUT OF BUILDING
RUBELLA	HIT BY BICYCLE	HIT BY FALLING OBJECT
VITAMIN D DEFICIENCY	LIGHTNING	FIREARM ACCIDENT
RICKETTS	CATACLYSM	EXCESSIVE COLD
HIT BY TRAIN	BITES AND STINGS	ACCIDENTAL POISONING
PLANE CRASH		FALL FROM LADDER

Contrary to conventional wisdom, one cannot assume that the most downstream utility faces the greatest risk and therefor be the most vulnerable. The total number of dischargers upstream from a utility is not the proper criterion to judge vulnerability. Vulnerability depends on relative locations of intakes and outfalls, flow and persistance of the pollutants. Table 32 ranks the utilities from most vulnerable to least vulnerable, their river mile and the expected number of deaths per year due to carcinogens.

TABLE 32

SUMMARY OF VULNERABLILITY FOR CARCINOGENIC POLLUTANTS AT AVERAGE FLOW

Rank	Downstream Order	Utility	River Mile	Expected Number of deaths/100,000
1	5	Greenup, KY	334.7	6.47
2	6	Portsmouth, OH	355.5	5.01
3	7	Maysville, KY	408.4	2.99
4	8	Cincinnati Area	462.8	1.56
5	4	Ironton, OH	327.0	0.20
6	2	Huntington, W.VA	304.3	0.19
7	3	Ashland, KY	319.6	0.18
8	1	Gallipolis, OH	265.8	0.02

VARIATIONS IN FLOW

Assessing the vulnerabilty of utilities to carcinogens at high and low flow periods is not really necessary since it may require decades for symptoms to appear due to low daily exposures to carcinogens. However, simulating carcinogens at high and low flow scenarios is useful in identifying individual pollutants that could be of particular importance for acute health effects as well as chronic, plus rankings of vulnerablity may change due to travel times and decay rates as was shown for organoleptic and toxic pollutants. Regulatory agencies may want to use different flow scenarios to increase the safety factor in promulgating regulations.

Tables 33 through 40 display the risk levels for carcinogens at high and low flow scenarios. As expected, the overall number of expected deaths are lower at high flow due to the greater dilution of the pollutants at 220,000 cfs. However, there are a few carcinogens whose risk level increase at high flow as compared to average flow. Those pollutants are marked by an asterisk in Tables 33-40. Although the total expected deaths are lower at high flow than at average flow these individual pollutants exhibit higher concentrations due to their volatilization rates allowing more decay at average flow during the longer time-of-travel. This result once again points to the usefullness in modeling the water quality parameters since many pollutants are masked at various flow scenarios by the total expected number of deaths calculated. Once again, the concentrations at utilites during high flow such as Maysville and Cincinnati Area intakes for pollutants with high decay rates are greater than at average flow. The Huntington, Ashland and Ironton intakes also exhibit the same result

TABLE 33

EXPECTED DEATHS DUE TO CARCINOGENS AT GALLIPOLIS, OHIO

AT VARIOUS FLOWS

Pollutant	Average Flow	High Flow	Low Flow
Aldrin	0	0	0
α-BHC	0	0	0
β-BHC	0	0	0
γ-BHC	0	0	0
DDE	0	0	0
Dieldrin	0	0	0
Heptachlor	0	0	0
Arsenic	2.04×10^{-2}	1.15×10^{-2}	7.19×10^{-2}
Beryllium	0	0	0
PCB-1221	0	0	0
PCB-1232	0	0	0
PCB-1242	0	0	0
PCB-1248	0	0	0
PCB-1254	3.08×10^{-3}	*3.44×10^{-3}	*1.27×10^{-3}
Chloromethane	0	0	0
Dichloromethane	2.04×10^{-4}	1.51×10^{-4}	*5.63×10^{-5}
Chlorodibromomethane	0	0	0
Dichlorodibromomethane	0	0	0
Tribromomethane	0	0	0
Chloroform	2.00×10^{-4}	1.51×10^{-4}	*5.63×10^{-5}
Carbon Tetrachloride	0	0	0
Trichlorofluoromethane	0	0	0
Dichlorodifluoromethane	0	0	0
1,2-Dichloroethane	3.10×10^{-5}	2.83×10^{-5}	*1.03×10^{-5}
1,1,2-Trichloroethane	0	0	0
1,1,2,2-Tetrachloroethane	0	0	0
TCE	1.00×10^{-5}	9.99×10^{-6}	*2.84×10^{-6}
Tetrachloroethene	1.80×10^{-5}	1.69×10^{-5}	*4.80×10^{-6}
Hexachlorobutadiene	0	0	0
Bis(chloromethyl)ether	0	0	0
Bis(2-chloroethyl)ether	0	0	0
Vinyl Chloride	0	0	0
Benzene	2.00×10^{-4}	*2.03×10^{-5}	*7.77×10^{-6}
2,4-Dinitrotoluene	0	0	0
Acenaphthylene	0	0	0
Anthracene	0	0	0
Benzo(a)anthracene	0	0	0
Benzo(ghi)perylene	0	0	0
Chrysene	0	0	0
Fluorene	0	0	0
Phenanthrene	0	0	0
Pyrene	0	0	0
Diphenylnitrosamine	0	0	0
Acrylonitrile	0	0	0
Total Expected Deaths =	.0249	.0046	.0733

TABLE 34

EXPECTED DEATHS DUE TO CARCINOGENS AT HUNTINGTON, WEST VIRGINIA AT VARIOUS FLOWS

Pollutant	Average Flow	High Flow	Low Flow
Aldrin	1.93×10^{-4}	0	3.96×10^{-4}
α-BHC	1.94×10^{-5}	1.30×10^{-5}	5.84×10^{-5}
β-BHC	3.20×10^{-6}	2.13×10^{-6}	1.07×10^{-5}
γ-BHC	2.30×10^{-6}	1.54×10^{-6}	6.91×10^{-6}
DDE	0	0	5.96×10^{-4}
Dieldrin	2.01×10^{-4}	0	4.03×10^{-4}
Heptachlor	0	0	7.14×10^{-5}
Arsenic	2.00×10^{-2}	1.17×10^{-2}	7.00×10^{-2}
Beryllium	5.67×10^{-5}	3.16×10^{-5}	2.01×10^{-4}
PCB-1221	0	0	1.81×10^{-4}
PCB-1232	1.81×10^{-4}	0	3.64×10^{-4}
PCB-1242	0	0	1.81×10^{-4}
PCB-1248	0	0	1.81×10^{-4}
PCB-1254	2.53×10^{-3}	$^*2.71 \times 10^{-3}$	$^*3.64 \times 10^{-4}$
Chloromethane	3.09×10^{-6}	1.96×10^{-6}	5.94×10^{-6}
Dichloromethane	1.12×10^{-4}	$^*1.20 \times 10^{-4}$	$^*2.09 \times 10^{-5}$
Chlorodibromomethane	3.39×10^{-6}	2.10×10^{-6}	7.97×10^{-6}
Dichlorodibromomethane	3.16×10^{-6}	2.03×10^{-6}	6.47×10^{-6}
Tribromomethane	1.66×10^{-6}	1.06×10^{-6}	3.69×10^{-6}
Chloroform	1.12×10^{-4}	$^*1.20 \times 10^{-4}$	$^*2.09 \times 10^{-5}$
Carbon Tetrachloride	7.14×10^{-7}	4.64×10^{-7}	1.36×10^{-6}
Trichlorofluoromethane	3.16×10^{-6}	1.96×10^{-6}	6.24×10^{-6}
Dichlorodifluoromethane	3.01×10^{-6}	1.96×10^{-6}	5.49×10^{-6}
1,2-Dichloroethane	2.07×10^{-5}	$^*2.23 \times 10^{-5}$	$^*3.87 \times 10^{-6}$
1,1,2-Trichloroethane	1.02×10^{-6}	6.43×10^{-7}	2.19×10^{-6}
1,1,2,2-Tetrachloroethane	1.84×10^{-6}	1.09×10^{-6}	3.94×10^{-6}
TCE	6.76×10^{-6}	$^*7.73 \times 10^{-6}$	$^*1.05 \times 10^{-6}$
Tetrachloroethene	1.14×10^{-5}	$^*1.30 \times 10^{-5}$	$^*1.77 \times 10^{-6}$
Hexachlorobutadiene	3.19×10^{-7}	1.91×10^{-7}	5.76×10^{-7}
Bis(chloromethyl)ether	1.70×10^{-1}	2.26×10^{-2}	3.70×10^{-7}
Bis(2-chloroethyl)ether	2.53×10^{-5}	1.29×10^{-5}	* 0
Vinyl Chloride	3.86×10^{-7}	2.21×10^{-7}	1.37×10^{-6}
Benzene	1.51×10^{-5}	$^*1.61 \times 10^{-5}$	$^*2.93 \times 10^{-6}$
2,4-Dinitrotoluene	3.50×10^{-6}	1.94×10^{-6}	1.21×10^{-5}
Acenaphthylene	2.04×10^{-5}	1.53×10^{-5}	4.59×10^{-5}
Anthracene	2.04×10^{-5}	1.53×10^{-5}	4.59×10^{-5}
Benzo(a)anthracene	5.10×10^{-6}	0	1.02×10^{-5}
Benzo(ghi)perylene	5.10×10^{-6}	0	1.02×10^{-5}
Chrysene	5.10×10^{-6}	0	1.02×10^{-5}
Fluorene	2.04×10^{-5}	1.53×10^{-5}	4.09×10^{-5}
Phenanthrene	2.04×10^{-5}	$^*4.09 \times 10^{-5}$	5.10×10^{-5}
Pyrene	0	0	1.02×10^{-5}
Diphenylnitrosamine	5.83×10^{-9}	2.91×10^{-9}	1.17×10^{-8}
Acrylonitrile	5.17×10^{-7}	2.46×10^{-7}	1.73×10^{-6}
Total Expected Deaths	.1936	.0375	.4434

TABLE 35

EXPECTED DEATHS DUE TO CARCINOGENS AT ASHLAND, KENTUCKY AT VARIOUS FLOWS

Pollutant	Average Flow	High Flow	Low Flow
Aldrin	0	0	1.93×10^{-4}
α-BHC	1.30×10^{-5}	6.50×10^{-6}	4.94×10^{-5}
β-BHC	2.13×10^{-6}	1.07×10^{-6}	8.53×10^{-6}
γ-BHC	1.54×10^{-6}	7.69×10^{-7}	6.14×10^{-6}
DDE	0	0	5.96×10^{-4}
Dieldrin	0	0	4.03×10^{-4}
Heptachlor	0	0	7.14×10^{-5}
Arsenic	6.00×10^{-2}	3.26×10^{-2}	2.03×10^{-1}
Beryllium	9.91×10^{-4}	5.61×10^{-4}	3.50×10^{-3}
PCB-1221	0	0	1.81×10^{-4}
PCB-1232	0	0	1.81×10^{-4}
PCB-1242	0	0	0
PCB-1248	0	0	0
PCB-1254	1.81×10^{-3}	$^*1.99 \times 10^{-3}$	$^*1.81 \times 10^{-4}$
Chloromethane	2.21×10^{-6}	1.50×10^{-6}	2.56×10^{-6}
Dichloromethane	7.96×10^{-5}	$^*9.23 \times 10^{-5}$	$^*9.70 \times 10^{-6}$
Chlorodibromomethane	2.56×10^{-6}	1.66×10^{-6}	4.36×10^{-6}
Dichlorodibromomethane	2.26×10^{-6}	1.50×10^{-6}	3.01×10^{-6}
Tribromomethane	1.20×10^{-6}	8.27×10^{-7}	1.89×10^{-6}
Chloroform	7.96×10^{-5}	$^*9.23 \times 10^{-5}$	$^*9.70 \times 10^{-6}$
Carbon Tetrachloride	5.00×10^{-7}	3.57×10^{-7}	5.71×10^{-7}
Trichlorofluoromethane	2.26×10^{-6}	1.50×10^{-6}	2.86×10^{-6}
Dichlorodifluoromethane	2.10×10^{-6}	1.43×10^{-6}	2.26×10^{-6}
1,2-Dichloroethane	1.54×10^{-5}	$^*1.71 \times 10^{-5}$	$^*1.77 \times 10^{-6}$
1,1,2-Trichloroethane	7.39×10^{-7}	5.00×10^{-7}	1.07×10^{-6}
1,1,2,2-Tetrachloroethane	1.34×10^{-6}	8.4×10^{-7}	1.93×10^{-6}
TCE	4.70×10^{-6}	$^*5.87 \times 10^{-6}$	$^*4.60 \times 10^{-7}$
Tetrachloroethene	7.93×10^{-6}	$^*9.90 \times 10^{-6}$	$^*7.69 \times 10^{-7}$
Hexachlorobutadiene	2.24×10^{-7}	1.60×10^{-7}	2.56×10^{-7}
Bis(chloromethyl)ether	1.20×10^{-1}	7.9×10^{-2}	1.91×10^{-1}
Bis(2-chloroethyl)ether	2.10×10^{-5}	1.19×10^{-5}	6.67×10^{-5}
Vinyl Chloride	3.29×10^{-7}	1.86×10^{-7}	1.16×10^{-6}
Benzene	1.08×10^{-5}	$^*1.24 \times 10^{-5}$	$^*1.36 \times 10^{-6}$
2,4-Dinitrotoluene	2.99×10^{-6}	1.69×10^{-6}	1.01×10^{-5}
Acenaphthyiene	1.53×10^{-5}	1.02×10^{-5}	2.04×10^{-5}
Anthracene	1.53×10^{-5}	1.02×10^{-5}	2.56×10^{-5}
Benzo(a)anthracene	0	0	1.02×10^{-5}
Benzo(ghi)perylene	0	0	0
Chrysene	0	0	1.02×10^{-5}
Fluorene	1.53×10^{-5}	1.02×10^{-5}	$^*1.53 \times 10^{-5}$
Phenanthrene	1.53×10^{-5}	1.02×10^{-5}	2.56×10^{-5}
Pyrene	0	0	1.02×10^{-5}
Acrylonitrile	4.93×10^{-7}	2.46×10^{-7}	9.86×15^{-7}
Diphenylnitrosamine	5.83×10^{-9}	2.91×10^{-9}	$^*5.83 \times 10^{-9}$
Total Expected Deaths	.1831	.1141	.3996

TABLE 36

EXPECTED DEATHS DUE TO CARCINOGENS AT IRONTON, OHIO AT VARIOUS FLOWS

Pollutant	Average Flow	High Flow	Low Flow
Aldrin	0	0	1.93 x 10^{-4}
α-BHC	1.30 x 10^{-5}	6.50 x 10^{-6}	5.20 x 10^{-5}
β-BHC	2.13 x 10^{-6}	1.07 x 10^{-6}	8.53 x 10^{-6}
γ-BHC	1.54 x 10^{-6}	7.68 x 10^{-7}	6.14 x 10^{-6}
DDE	0	0	0
Dieldrin	0	0	4.03 x 10^{-4}
Heptachlor	0	0	0
Arsenic	8.00 x 10^{-2}	4.71 x 10^{-2}	2.90 x 10^{-2}
Beryllium	1.00 x 10^{-2}	4.37 x 10^{-3}	3.00 x 10^{-2}
PCB-1221	0	0	0
PCB-1232	0	0	1.83 x 10^{-4}
PCB-1242	0	0	0
PCB-1248	0	0	0
PCB-1254	1.63 x 10^{-3}	*1.99 x 10^{-3}	*1.88 x 10^{-4}
Chloromethane	1.89 x 10^{-6}	1.35 x 10^{-6}	*1.73 x 10^{-6}
Dichloromethane	1.76 x 10^{-4}	1.47 x 10^{-4}	3.10 x 10^{-4}
Chlorodibromomethane	2.33 x 10^{-6}	1.59 x 10^{-6}	3.31 x 10^{-6}
Dichlorodibromomethane	2.03 x 10^{-6}	1.43 x 10^{-6}	2.10 x 10^{-6}
Tribromomethane	1.13 x 10^{-6}	7.51 x 10^{-7}	1.35 x 10^{-6}
Chloroform	1.76 x 10^{-4}	1.47 x 10^{-4}	3.10 x 10^{-4}
Carbon Tetrachloride	4.29 x 10^{-7}	3.21 x 10^{-7}	*3.93 x 10^{-7}
Trichlorofluoromethane	1.96 x 10^{-6}	1.43 x 10^{-6}	*1.96 x 10^{-6}
Dichlorodifluoromethane	1.80 x 10^{-6}	1.35 x 10^{-6}	*1.50 x 10^{-6}
1,2-Dichloroethane	1.31 x 10^{-5}	*1.63 x 10^{-5}	*1.23 x 10^{-6}
1,1,2-Trichloroethane	6.67 x 10^{-7}	4.76 x 10^{-7}	7.86 x 10^{-7}
1,1,2,2-Tetrachloroethane	1.18 x 10^{-6}	8.4 x 10^{-7}	1.43 x 10^{-6}
TCE	1.14 x 10^{-5}	9.71 x 10^{-6}	2.10 x 10^{-5}
Tetrachloroethene	1.91 x 10^{-5}	1.64 x 10^{-5}	3.54 x 10^{-5}
Hexachlorobutadiene	1.91 x 10^{-7}	1.28 x 10^{-7}	*1.60 x 10^{-7}
Bis(chloromethyl)ether	1.10 x 10^{-1}	7.51 x 10^{-2}	1.40 x 10^{-1}
Bis(2-chloroethyl)ether	2.10 x 10^{-5}	1.19 x 10^{-5}	6.39 x 10^{-5}
Vinyl Chloride	3.29 x 10^{-7}	1.86 x 10^{-7}	1.16 x 10^{-6}
Benzene	9.64 x 10^{-6}	1.16 x 10^{-5}	*9.53 x 10^{-7}
2,4-Dinitrotoluene	2.99 x 10^{-6}	*1.69 x 10^{-6}	9.87 x 10^{-6}
Acenaphthylene	1.53 x 10^{-5}	1.02 x 10^{-5}	*1.53 x 10^{-5}
Anthracene	1.53 x 10^{-5}	1.02 x 10^{-5}	*1.53 x 10^{-5}
Benzo(a)anthracene	0	0	1.02 x 10^{-5}
Benzo(ghi)perylene	0	0	1.02 x 10^{-5}
Chrysene	0	0	1.02 x 10^{-5}
Fluorene	1.53 x 10^{-5}	0	*1.02 x 10^{-5}
Phenanthrene	1.53 x 10^{-5}	1.02 x 10^{-5}	2.04 x 15^{-5}
Pyrene	0	0	5.10 x 10^{-6}
Diphenylnitrosamine	2.91 x 10^{-9}	*2.91 x 10^{-9}	*2.91 x 10^{-9}
Acrylonitrile	4.93 x 10^{-7}	2.46 x 10^{-7}	9.86 x 10^{-7}
Total Expected Deaths	.2022	.1290	.4619

TABLE 37

EXPECTED DEATHS DUE TO CARCINOGENS AT GREENUP, KENTUCKY AT VARIOUS FLOWS

Pollutant	Average Flow	High Flow	Low Flow
Aldrin	3.47×10^{-3}	1.93×10^{-3}	1.20×10^{-2}
α-BHC	5.84×15^{-4}	3.31×10^{-4}	2.03×10^{-3}
β-BHC	9.60×10^{-5}	5.44×10^{-5}	2.36×10^{-4}
γ-BHC	6.83×10^{-5}	3.91×10^{-5}	2.40×10^{-4}
DDE	1.01×10^{-2}	5.96×10^{-3}	3.16×10^{-2}
Dieldrin	3.63×10^{-3}	2.01×10^{-3}	1.27×10^{-2}
Heptachlor	1.21×10^{-3}	7.14×10^{-4}	3.64×10^{-3}
Arsenic	9.00×10^{-2}	5.04×10^{-2}	3.14×10^{-1}
Beryllium	1.00×10^{-2}	5.41×10^{-3}	3.37×10^{-2}
PCB-1221	3.07×10^{-3}	1.81×10^{-3}	9.59×10^{-3}
PCB-1232	3.26×10^{-3}	1.81×10^{-3}	1.12×10^{-2}
PCB-1242	2.07×10^{-3}	$1.81 \times 10^{-}$	9.04×10^{-3}
PCB-1248	3.07×10^{-3}	1.81×10^{-3}	9.04×10^{-3}
PCB-1254	1.44×10^{-3}	*1.81×10^{-3}	* 0.00
Chloromethane	1.24×10^{-4}	7.24×10^{-5}	3.63×10^{-4}
Dichloromethane	2.81×10^{-4}	2.10×10^{-4}	5.94×10^{-4}
Chlorodibromomethane	1.27×10^{-4}	7.37×10^{-5}	3.94×10^{-4}
Dichlorodibromomethane	1.25×10^{-4}	7.27×10^{-5}	3.71×10^{-4}
Tribromomethane	6.31×10^{-5}	3.66×10^{-5}	1.93×10^{-4}
Chloroform	2.96×10^{-4}	2.16×10^{-4}	6.23×10^{-4}
Carbon Tetrachloride	2.93×10^{-5}	1.71×10^{-5}	8.56×10^{-4}
Trichlorofluoromethane	1.24×10^{-4}	7.26×10^{-5}	3.69×10^{-4}
Dichlorodifluoromethane	1.23×10^{-4}	7.21×10^{-5}	3.56×10^{-4}
1,2-Dichloroethane	3.67×10^{-5}	2.96×10^{-5}	7.54×10^{-5}
1,1,2-Trichloroethane	3.97×10^{-5}	2.31×10^{-5}	1.20×10^{-4}
1,1,2,2-Tetrachloroethane	7.03×10^{-5}	4.09×10^{-5}	2.13×10^{-4}
TCE	1.89×10^{-5}	1.41×10^{-5}	4.01×10^{-5}
Tetrachloroethene	3.27×10^{-5}	2.44×10^{-5}	7.11×10^{-5}
Hexachlorobutadiene	1.30×10^{-5}	7.67×10^{-6}	3.79×10^{-5}
Bis(chloromethyl)ether	6.33	3.67	19.30
Bis(2-chloroethyl)ether	8.47×10^{-4}	4.80×10^{-4}	2.91×10^{-3}
Vinyl Chloride	1.28×10^{-5}	7.24×10^{-6}	4.50×10^{-5}
Benzene	2.77×10^{-5}	2.20×10^{-5}	5.80×10^{-5}
2,4-Dinitrotoluene	1.16×10^{-4}	6.57×10^{-5}	4.06×10^{-4}
Acenaphthylene	8.47×10^{-4}	4.94×10^{-4}	2.54×10^{-3}
Anthracene	8.51×10^{-4}	4.94×10^{-4}	2.57×10^{-3}
Benzo(a)anthracene	9.19×10^{-5}	5.10×10^{-5}	3.21×10^{-4}
Benzo(ghi)perylene	9.19×10^{-5}	5.10×10^{-5}	3.21×10^{-4}
Chrysene	9.19×10^{-5}	5.10×10^{-5}	3.21×10^{-4}
Fluorene	8.37×10^{-4}	4.9×10^{-4}	2.47×10^{-3}
Phenanthrene	8.57×10^{-4}	5.00×10^{-4}	2.63×10^{-3}
Pyrene	9.19×10^{-5}	5.10×10^{-5}	3.16×10^{-4}
Diphenylnitrosamine	2.41×10^{-7}	1.40×1^{-7}	7.20×10^{-7}
Acrylonitrile	2.14×10^{-5}	1.23×10^{-5}	6.90×10^{-5}
Total Expected Deaths	6.4694	3.7497	19.7680

TABLE 38

EXPECTED DEATHS DUE TO CARCINOGENS AT PORTSMOUTH, OHIO AT VARIOUS FLOWS

Pollutant	Average Flow	High Flow	Low Flow
Aldrin	3.09×10^{-3}	1.74×10^{-3}	1.02×10^{-2}
α-BHC	5.33×10^{-4}	3.06×10^{-4}	1.83×10^{-3}
β-BHC	8.84×10^{-5}	5.01×10^{-5}	3.11×10^{-4}
γ-BHC	6.30×10^{-5}	3.61×10^{-5}	2.14×10^{-4}
DDE	8.33×10^{-3}	4.76×10^{-3}	1.79×10^{-2}
Dieldrin	3.41×10^{-3}	1.81×10^{-3}	1.17×10^{-2}
Heptachlor	9.29×10^{-4}	5.71×10^{-4}	1.93×10^{-3}
Arsenic	8.04×10^{-2}	4.67×10^{-2}	2.09×10^{-1}
Beryllium	9.00×10^{-3}	5.01×10^{-3}	3.11×10^{-2}
PCB-1221	2.53×10^{-3}	1.44×10^{-3}	5.43×10^{-3}
PCB-1232	2.90×10^{-3}	1.63×10^{-3}	9.59×10^{-3}
PCB-1242	2.17×10^{-3}	1.44×10^{-3}	4.16×10^{-3}
PCB-1248	2.17×10^{-3}	1.44×10^{-3}	4.16×10^{-3}
PCB-1254	1.08×10^{-3}	1.44×10^{-3}	0.00
Chloromethane	8.99×10^{-5}	5.81×10^{-5}	1.54×10^{-4}
Dichloromethane	2.10×10^{-4}	1.71×10^{-4}	2.73×10^{-4}
Chlorodibromomethane	1.00×10^{-4}	6.21×10^{-5}	2.19×10^{-4}
Dichlorodibromomethane	9.27×10^{-5}	5.93×10^{-5}	1.70×10^{-4}
Tribromomethane	4.87×10^{-5}	3.06×10^{-5}	9.89×10^{-5}
Chloroform	2.16×10^{-4}	1.76×10^{-4}	2.86×10^{-4}
Carbon Tetrachloride	2.11×10^{-5}	1.37×10^{-5}	3.56×10^{-5}
Trichlorofluoromethane	9.17×10^{-5}	5.89×10^{-5}	1.66×10^{-4}
Dichlorodifluoromethane	8.76×10^{-5}	5.73×10^{-5}	1.43×10^{-4}
1,2-Dichloroethane	2.71×10^{-5}	2.40×10^{-5}	3.43×10^{-5}
1,1,2-Trichloroethane	3.01×10^{-5}	1.91×10^{-5}	5.87×10^{-5}
1,1,2,2-Tetrachloroethane	5.36×10^{-5}	3.37×10^{-5}	1.05×10^{-4}
TCE	1.37×10^{-5}	1.14×10^{-5}	1.71×10^{-5}
Tetrachloroethene	2.39×10^{-5}	1.97×10^{-5}	3.04×10^{-5}
Hexachlorobutadiene	9.30×10^{-6}	6.07×10^{-6}	1.51×10^{-5}
Bis(chloromethyl)ether	4.89	3.06	10.10
Bis(2-chloroethyl)ether	7.66×10^{-4}	4.39×10^{-4}	2.50×10^{-3}
Vinyl Chloride	1.19×10^{-5}	1.79×10^{-5}	4.17×10^{-5}
Benzene	2.06×10^{-5}	6.71×10^{-6}	2.67×10^{-5}
2,4-Dinitrotoluene	1.07×10^{-4}	6.06×10^{-5}	3.66×10^{-4}
Acenaphthylene	6.37×10^{-4}	4.03×10^{-4}	1.20×10^{-3}
Anthracene	6.49×10^{-4}	4.09×10^{-4}	1.26×10^{-3}
Benzo(a)anthracene	8.67×10^{-5}	4.49×10^{-5}	2.96×10^{-4}
Benzo(ghi)perylene	8.67×10^{-5}	4.59×10^{-5}	2.96×10^{-4}
Chrysene	8.67×10^{-5}	4.59×10^{-5}	2.96×10^{-4}
Fluorene	6.07×10^{-4}	3.93×10^{-4}	1.05×10^{-3}
Phenanthrene	6.63×10^{-4}	4.13×10^{-4}	1.36×10^{-3}
Pyrene	8.16×10^{-5}	4.59×10^{-5}	2.90×10^{-4}
Diphenylnitrosamine	1.81×10^{-7}	1.14×10^{-7}	3.33×10^{-7}
Acrylonitrile	1.77×10^{-5}	1.06×10^{-5}	4.60×10^{-5}
Total Expected Deaths	5.0110	3.1366	10.4183

TABLE 39

EXPECTED DEATHS DUE TO CARCINOGENS AT MAYSVILLE, KENTUCKY AT VARIOUS FLOWS

Pollutant	Average Flow	High Flow	Low Flow
Aldrin	2.90×10^{-3}	1.74×10^{-3}	8.50×10^{-3}
α-BHC	5.13×10^{-4}	2.93×10^{-4}	1.67×10^{-3}
β-BHC	8.74×10^{-5}	4.90×10^{-5}	3.06×10^{-4}
γ-BHC	5.99×10^{-5}	3.46×10^{-5}	1.93×10^{-4}
DDE	5.36×10^{-3}	3.57×10^{-3}	*4.76×10^{-3}
Dieldrin	3.21×10^{-3}	1.81×10^{-3}	1.15×10^{-2}
Heptachlor	5.71×10^{-4}	4.29×10^{-4}	*3.57×10^{-4}
Arsenic	8.13×10^{-2}	4.60×10^{-2}	2.86×10^{-1}
Beryllium	8.70×10^{-3}	4.91×10^{-3}	3.07×10^{-2}
PCB-1221	1.63×10^{-3}	1.08×10^{-3}	*1.44×10^{-3}
PCB-1232	2.71×10^{-3}	1.63×10^{-3}	7.96×10^{-3}
PCB-1242	1.27×10^{-3}	1.08×10^{-3}	*7.23×10^{-4}
PCB-1248	1.27×10^{-3}	1.08×10^{-3}	*5.43×10^{-4}
PCB-1254	5.43×10^{-4}	*1.08×10^{-3}	* 0.00
Chloromethane	5.07×10^{-5}	3.91×10^{-5}	*1.83×10^{-5}
Dichloromethane	1.14×10^{-4}	*1.20×10^{-4}	*3.94×10^{-5}
Chlorodibromomethane	6.43×10^{-5}	4.76×10^{-5}	*5.24×10^{-5}
Dichlorodibromomethane	5.07×10^{-5}	4.14×10^{-5}	*2.47×10^{-5}
Tribromomethane	2.93×10^{-5}	2.26×10^{-5}	*1.93×10^{-5}
Chloroform	1.18×10^{-4}	*1.23×10^{-4}	*4.13×10^{-5}
Carbon Tetrachloride	1.06×10^{-5}	9.14×10^{-6}	*2.93×10^{-6}
Trichlorofluoromethane	4.91×10^{-5}	4.07×10^{-5}	*2.23×10^{-5}
Dichlorodifluoromethane	4.24×10^{-5}	3.74×10^{-5}	*1.43×10^{-5}
1,2-Dichloroethane	1.47×10^{-5}	†1.67×10^{-5}	*4.77×10^{-6}
1,1,2-Trichloroethane	1.74×10^{-5}	1.37×10^{-5}	*1.00×10^{-5}
1,1,2,2-Tetrachloroethane	3.11×10^{-5}	2.44×10^{-5}	*1.86×10^{-5}
TCE	7.00×10^{-6}	*7.64×10^{-6}	*2.03×10^{-6}
Tetrachloroethene	1.22×10^{-5}	*1.32×10^{-5}	*3.59×10^{-6}
Hexachlorobutadiene	4.54×10^{-6}	3.96×10^{-6}	*1.53×10^{-6}
Bis(chloromethyl)ether	2.97	2.27	* 2.03
Bis(2-chloroethyl)ether	7.04×10^{-4}	4.14×10^{-4}	1.97×10^{-3}
Vinyl Chloride	1.17×10^{-5}	*6.59×10^{-5}	4.10×10^{-5}
Benzene	1.12×10^{-5}	*1.25×10^{-5}	* $.86 \times 10^{-6}$
2,4-Dinitrotoluene	1.03×10^{-4}	5.87×10^{-5}	3.34×10^{-4}
Acenaphthylene	3.57×10^{-4}	2.86×10^{-4}	*2.44×10^{-4}
Anthracene	3.73×10^{-4}	2.96×10^{-4}	*2.80×10^{-4}
Benzo(a)anthracene	8.16×10^{-5}	4.59×10^{-5}	2.86×10^{-4}
Benzo(ghi)perylene	8.16×10^{-5}	4.59×10^{-5}	2.91×10^{-4}
Chrysene	8.16×10^{-5}	4.59×10^{-5}	2.86×10^{-4}
Fluorene	3.11×10^{-4}	2.66×10^{-4}	1.22×10^{-4}
Phenanthrene	4.03×10^{-4}	3.06×10^{-4}	2.76×10^{-4}
Pyrene	8.16×10^{-5}	4.59×10^{-5}	2.50×10^{-4}
Diphenylnitrosamine	9.91×10^{-8}	8.16×10^{-8}	*4.67×10^{-8}
Acrylonitrile	1.33×10^{-5}	8.87×10^{-6}	1.87×10^{-5}
Total Expected Deaths	2.9382	2.3372	*2.3893

TABLE 40

EXPECTED DEATHS DUE TO CARCINOGENS AT CINCINNATI AREA INTAKES AT VARIOUS FLOWS

Pollutant	Average Flow	High Flow	Low Flow
Aldrin	2.51 x 10^{-3}	1.54 x 10^{-3}	5.99 x 10^{-3}
α-BHC	4.49 x 10^{-4}	2.60 x 10^{-4}	1.38 x 10^{-4}
β-BHC	7.81 x 10^{-5}	4.47 x 10^{-5}	2.76 x 10^{-4}
γ-BHC	5.23 x 10^{-5}	3.07 x 10^{-5}	1.56 x 10^{-4}
DDE	2.98 x 10^{-3}	2.39 x 10^{-3}	*5.96 x 10^{-4}
Dieldrin	3.01 x 10^{-3}	1.61 x 10^{-3}	1.05 x 10^{-2}
Heptachlor	2.86 x 10^{-4}	*2.86 x 10^{-4}	*7.14 x 10^{-5}
Arsenic	7.34 x 10^{-2}	4.16 x 10^{-2}	2.59 x 10^{-1}
Beryllium	7.90 x 10^{-3}	4.44 x 10^{-3}	2.77 x 10^{-2}
PCB-1221	9.04 x 10^{-4}	7.23 x 10^{-4}	*1.81 x 10^{-4}
PCB-1232	2.36 x 10^{-3}	1.44 x 10^{-3}	5.60 x 10^{-3}
PCB-1242	5.43 x 10^{-4}	*5.43 x 10^{-4}	* 0
PCB-1248	5.43 x 10^{-4}	*5.43 x 10^{-4}	* 0
PCB-1254	1.81 x 10^{-4}	*5.43 x 10^{-4}	* 0
Chloromethane	1.83 x 10^{-5}	*2.20 x 10^{-5}	*1.20 x 10^{-6}
Dichloromethane	4.91 x 10^{-5}	*2.06 x 10^{-5}	*3.23 x 10^{-6}
Chlorodibromomethane	3.37 x 10^{-5}	*3.16 x 10^{-5}	*8.04 x 10^{-6}
Dichlorodibromomethane	2.19 x 10^{-5}	*2.44 x 10^{-5}	*2.03 x 10^{-6}
Tribromomethane	1.41 x 10^{-5}	*1.42 x 10^{-5}	*2.33 x 10^{-6}
Chloroform	5.07 x 10^{-5}	*7.23 x 10^{-5}	*3.39 x 10^{-6}
Carbon Tetrachloride	4.11 x 10^{-6}	*5.07 x 10^{-6}	*2.14 x 10^{-7}
Trichlorofluoromethane	2.06 x 10^{-5}	*2.36 x 10^{-5}	*1.66 x 10^{-6}
Dichlorodifluoromethane	1.51 x 10^{-5}	*2.03 x 10^{-5}	*7.51 x 10^{-7}
1,2-Dichloroethane	6.23 x 10^{-6}	*9.76 x 10^{-6}	*3.80 x 10^{-7}
1,1,2-Trichloroethane	7.97 x 10^{-6}	*8.40 x 10^{-6}	*1.00 x 10^{-6}
1,1,2,2-Tetrachloroethane	1.46 x 10^{-5}	*1.51 x 10^{-5}	*1.93 x 10^{-6}
TCE	2.79 x 10^{-6}	*4.30 x 10^{-6}	*1.27 x 10^{-7}
Tetrachloroethene	4.68 x 10^{-6}	*7.43 x 10^{-6}	*2.33 x 10^{-7}
Hexachlorobutadiene	1.70 x 10^{-6}	*2.14 x 10^{-6}	*6.09 x 10^{-8}
Bis(chloromethyl)ether	1.46	1.44	*2.51 x 10^{-1}
Bis(2-chloroethyl)ether	5.87 x 10^{-4}	3.57 x 10^{-4}	1.36 x 10^{-3}
Vinyl Chloride	1.05 x 10^{-5}	7.36 x 10^{-6}	3.70 x 10^{-5}
Benzene	4.83 x 10^{-6}	*5.96 x 10^{-6}	*3.24 x 10^{-7}
2,4-Dinitrotoluene	9.01 x 10^{-5}	5.23 x 10^{-5}	2.76 x 10^{-4}
Acenaphthylene	1.59 x 10^{-4}	*1.73 x 10^{-4}	*2.04 x 10^{-5}
Anthracene	1.71 x 10^{-4}	*1.79 x 10^{-4}	*3.06 x 10^{-5}
Benzo(a)anthracene	7.66 x 10^{-5}	4.09 x 10^{-5}	2.56 x 10^{-4}
Benzo(ghi)perylene	7.66 x 10^{-5}	4.09 x 10^{-5}	2.66 x 10^{-4}
Chrysene	7.66 x 10^{-5}	4.09 x 10^{-5}	2.56 x 10^{-4}
Fluorene	1.22 x 10^{-4}	*1.49 x 10^{-4}	*1.02 x 10^{-5}
Phenanthrene	1.99 x 10^{-4}	1.94 x 10^{-4}	*3.57 x 10^{-5}
Pyrene	6.63 x 10^{-5}	4.08 x 10^{-5}	1.94 x 10^{-4}
Diphenylnitrosamine	4.09 x 10^{-8}	4.67 x 10^{-8}	*2.91 x 10^{-9}
Acrylonitrile	9.26 x 10^{-6}	6.66 x 10^{-6}	*5.41 x 10^{-6}
Total Expected Deaths	1.5571	1.5000	.5646

for pollutants coming from the Kanawha River. The decreased time-of-travel at high flow has not allowed for the pollutant to decay, thus utilities well downstream are at higher risk during high flow periods and consequently are at low risk during low flow due to the long travel times. Utilities closest to the outfalls would exhibit expected risk levels; highest risk at low flow and lowest risk at high flow regardless of decay rates.

Tables 33 through 40 also display the risk levels for the utilities during low flow periods. Those pollutants at low flow whose concentration is less than or equal to those at average flow due to time-of-travel and decay rates are also marked by an asterisk. Those pollutants identified at high and low flow scenarios not conforming to the expected pattern all have decay rates >.38/day. Two pesticides are represented, four of the five PCB compounds, as are almost all of the halogenated aliphatics (halomethanes) and assorted ether monocyclic aromatics, polycyclic aromatic hydrocarbons and two nitrogen containing compounds.

Table 41 summarizes the vulnerability rankings at the different flow scenarios.

TABLE 41

VULNERABILITY OF UTILITIES AT VARIOUS FLOW SCENARIOS FOR CARCINOGENS

Utility	Expected Deaths at Average Flow	Expected Deaths at High Flow	Expected Deaths at Low Flow
Greenup, KY	6.47(1)	3.75(1)	19.77(1)
Portsmouth, OH	5.01(2)	3.14(2)	10.42(2)
Maysville, KY	2.99(3)	2.34(3)	*2.39(3)
Cincinnati Area	1.56(4)	1.50(4)	*0.56(4)
Ironton, OH	0.20(5)	0.13(5)	0.46(5)
Huntington, WV	0.19(6)	0.04(7)	0.44(6)
Ashland, KY	0.18(7)	0.11(6)	0.40(7)
Gallipolis, KY	0.02(8)	0.01(8)	0.07(8)

( ) Rank

As can be seen there is little variation in rankings over the various flows. However, as discussed previously, there can be large variations in risk during different flow scenarios for individual pollutants. Only Huntington, WV and Ashland, KY reverse positions in vulnerability at high flow. The big surprise is the actual number of deaths expected at Maysville, KY and Cincinnati Area intakes at low flow. Due to their extreme downstream location with long travel-times, and little or no industrial waste discharged near their intakes upstream, pollutant concentrations have decayed to a point where risk levels are higher or nearly equal at average and high flows. However, at Greenup, KY and Portsmouth, OH, the risk levels are much higher at low flow as traditionally expected.

Thus, it seems that the issue of vulnerability is not a clear-cut problem of looking for the most downstream utility or simulating pollutants at an average flow. Very detailed information on flow probabilities, pollutant characteristics, discharge flow and location are needed.

OHIO RIVER VALLEY SPILL ANALYSIS

For more than 20 years, the Ohio River Valley Water Sanitation Commission (ORSANCO) has been concerned about the frequency of spills in the heavily industrialized Ohio Valley. In addition to ORSANCO's resolution No. 14-59 requiring notification of spills and information on time and place of spill, type and quantity of discharge and actions taken to minimize the pollutional effect, the outburst of Federal environmental legislation in the 1970's has resulted in each U.S. EPA regional office and state pollution control offices to develop a spill response program (ORSANCO, 1978).

At the Cincinnati headquarters of ORSANCO, spill reports are received almost daily. A total of 150 spills were reported in 1978, 161 similar reports were received in 1979. The monthly average was 13, with 20 as the highest single month. There does not seem to be any monthly or seasonal trend. Spills of less than five gallons are not reported to ORSANCO thus possibly under-representing spill frequency by a large number.

Most spills occur in the Pittsburgh-Wheeling area, Kanawha River area and Cincinnati locale. The length of river from Cincinnati to its confluence with the Mississippi is almost spill free. Many spills do not reach the Ohio mainstem. Truck and rail accidents may result in a sizeable discharge of a chemical to a tributary where it may be cleaned up or contained.

Accidental discharges occur in every conceivable place and manner. The leading category of spills is industrial. Most disharges originate within a plant due to untrained workers, carelessness or lagoon dike failures following unfavorable weather. A large portion of reported spills happen during transportation of industrial fluids. This includes barge accidents, train derailments, truck collisions and overturns. Barge accidents, although less frequent, are more threatening due to the volume and direct discharge into the river with little chance of recovery (Kroner, 1980).

Of course clandestine dumping practices still exist. Of these, the most infamous discharge involved the FMC plant at South Charleston, WVA in February, 1977. A survey by EPA personnel pinpointed the FMC plant as the source of a massive carbon tetrachloride discharge initially reported to be about 70 tons. Further investigation indicated the discharge could have been as much as 200 tons. Records revealed daily discharges of almost 3000 pounds rather than the reported values of less than 300 pounds per day permitted. FMC pleaded guility to 5 of 6 indictments and agreed to pay a total fine of $35,000. Charges were dropped against two employees by the government and the corporation agreeded to pay into an environmental trust fund $1,000,000 (Daum, 1981).

QUAL-II Simulations of Carbon Tetrachloride

EPA sampling recorded carbon tetrachloride levels at Cincinnati, OH as high as 110 ug/L following the FMC discharge (Love and Eilers, 1982). During January and February of 1977 when the discharge occurred, the Ohio River was at low flow with substantial ice over for almost 800 of the river's 981 miles. Due to the ice cover, volatilization was substantially reduced. Assuming no volatilization, QUAL-II estimated that a 60-ton discharge at the FMC plant would be necessary in order that concentrations of 110 ug/L be found downstream at Cincinnati. As can be seen in Figure 9 the actual concentration shows two peaks while the simulation only one. QUAL-II assumes a continuous discharge throughout the time of the discharge whereas in reality the carbon tetrachloride could have been discharged in spurts over the course of a few days.

Based on the flow data and subsequent time-of-travel calculations, a 60 ton spill would take approximately three weeks to reach the Cincinnati area intakes from the FMC plant. Flows for the Ohio River for January through mid-February were consistently less than 35,000 CFS (low flow) (McPhillips, 1982). From Figure 9 it would seem that there were probably two separate discharges of carbon tetrachloride of similar magnitude, the

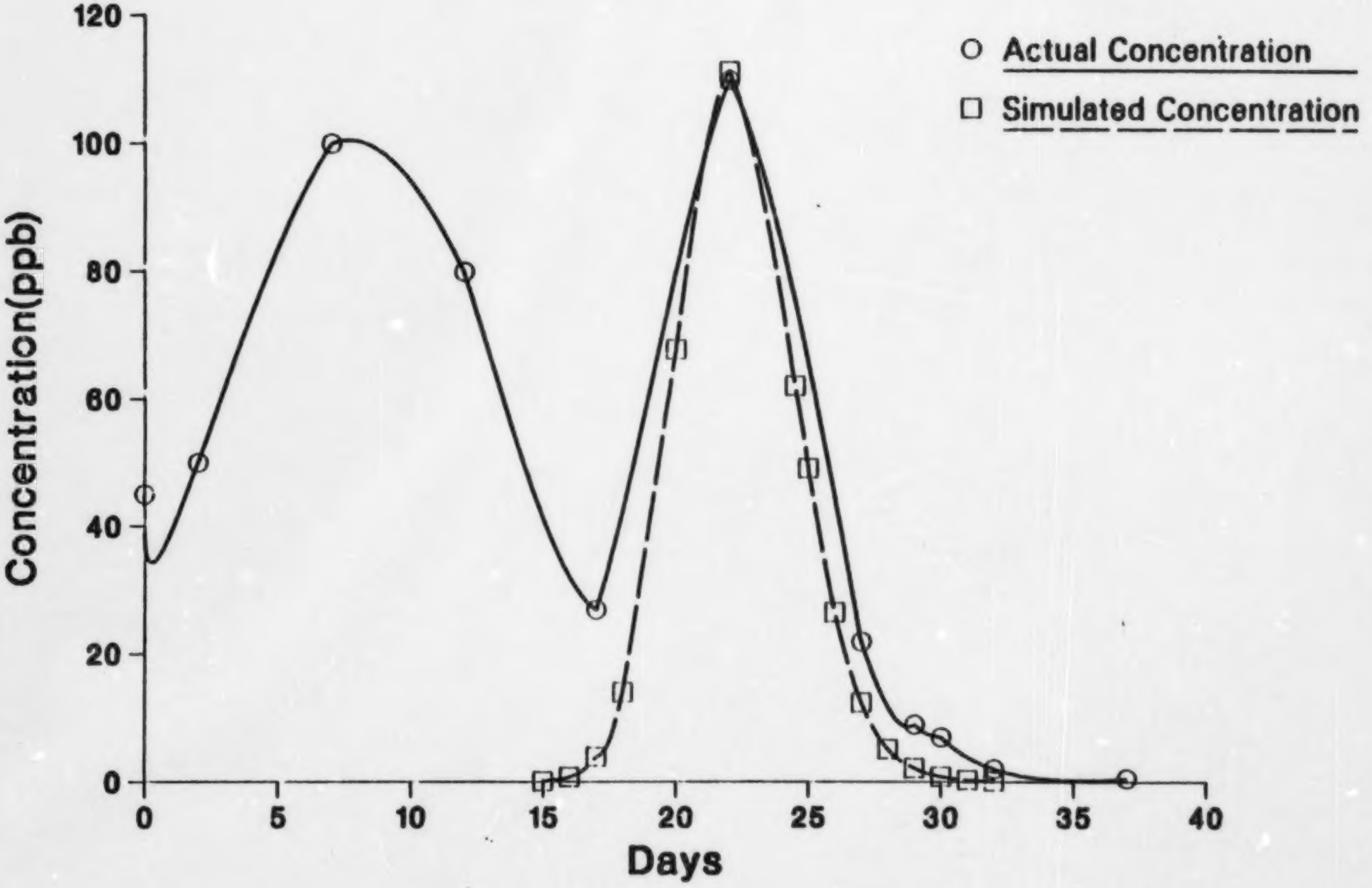

Figure 9. Actual vs. Simulated Carbon Tetrachloride Concentrations at Cincinnati, Ohio

first being in early January and the second approximately two weeks later that gained the media attention. A one day discharge of 60 tons of carbon tetrachloride would result in the simulated curve in Figure 9. As can be seen there was much more carbon tetrachloride already passing by the intakes.

Due to barge traffic and weather conditions neither the Ohio nor the Kanawha River were totally covered with ice. Therefore, some volatilization probably took place, thus requiring a larger initial discharge, consistent with preliminary EPA estimates of 70 tons.

There is a great deal of sensitivity between the factors of volatility, flow and the initial concentration of a spill. A 200-ton discharge of carbon tetrachloride with no decay at low flow would have resulted in a concentration of 366 ug/L at Cincinnati area intakes, so it seems unlikely that the discharge was that massive.

Had the Ohio River been at high flow, concentrations at Cincinnati would have only been approximately 50 ug/L assuming no volatilization. However, at high flow, ice cover is unlikely and volatilization would occur. A 200-ton spill at FMC with the calculaterd decay rate of .63/day, used in the daily discharge analysis, would result in only 5.5 ug/L of carbon tetrachloride being found in the raw water at Cincinnati area intakes. A 60-ton spill at high flow with volatilization would result in only 1.66 ug/L being present. So it is obvious that the discharge size, the amount of flow and volatilization are vital to the estimation of concentrations of pollutants at an intake, hence the vulnerability of the community.

The peak concentration is not the only important statistic to be concerned with. The length of time it takes for a spill to pass the intakes is also vital to a community's welfare. The shape of the curve of the spill as well as the peak must be considered in terms of how long a utility can close its intakes and allow the spill to pass. A slow passing spill although of lower concentration may pose a larger problem to a utility with limited storage capability than a very high concentration of a pollutant that passes quickly. Figure 10 shows the simulated concentrations of the 60-ton carbon tetrachloride discharge as it passes Gallipolis, OH at various flows and .63/day decay rate. At high flow, the spill would take almost 2-days to pass the Gallipolis intake. Average and low flow scenarios would require 3.5 and 9 days respectively to pass. As can be seen, the high flow concentration is very high, but Gallipolis has 2-days storage available (see Table 9) and could close the intake and not be harmed. However, at average and low flows, the spill requires a longer time to pass and Gallipolis utility officials would need immediate and accurate information regarding the discharge in order to be able decide when to close the intakes and reduce the exposure to the pollutant. Proper timing of the closure during the peak of the curve could reduce the health risks immensely.

Closing the intake 1.5 days after the discharge for 2-days, during the average flow scenario would result in only very low concentrations of carbon tetrachloride being drawn into the intake. Concentrations of carbon tetrachloride in the tails of the curve are in the parts per trillion range and pose little health threat. During low flow the intakes should

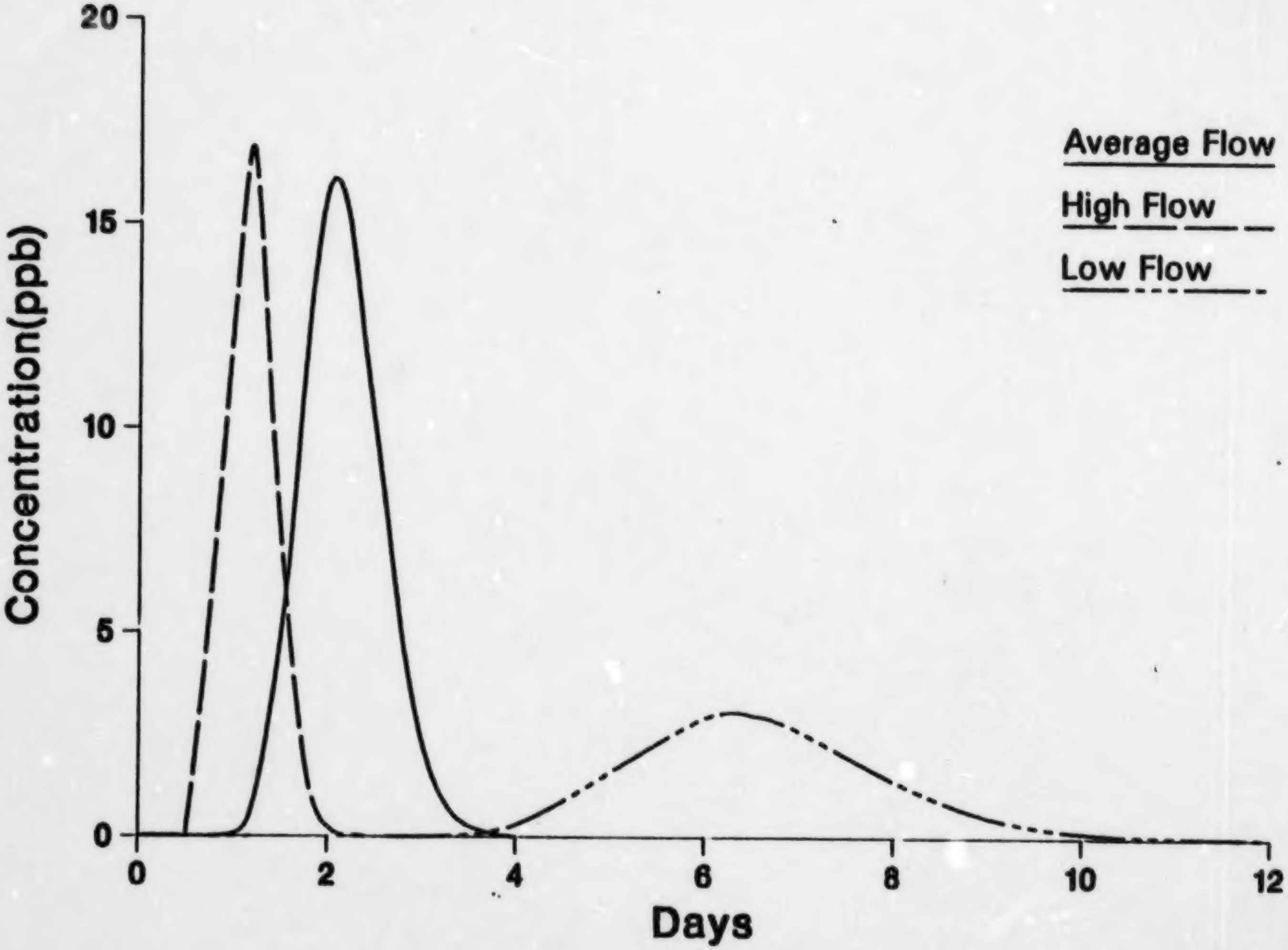

Figure 10. Carbon Tetrachloride Concentrations
at Gallipolis, Ohio During
Various Flow Scenarios

be closed from the fifth to the seventh day after discharge to minimize exposure to the highest levels of carbon tetrachloride.

Another important factor that affects peak concentration and length of time for a discharge to pass an intake is the persistence of the pollutant. Figure 12 shows the simulated concentration of a pollutant with various decay rates at average flow. These simulations could represent carbon tetrachloride with a normal decay of .63/day with various levels of ice cover cutting its volatilization in half until finally no decay other than dilution occurs. This figure could also represent three separate pollutants with varying decay rates under average conditions and no ice cover.

As can be seen in Figure 11 as decay rate decreases, not only does the peak concentration increase, the time-of-passage increases. A worst case scenario would include a nonvolatile, hightly toxic pollutant, discharged during a low flow period. However, this would not be a total disaster since the slow time-of-travel would allow ample time for downstream utilities to take precautionary measures, possibly even altering treatment techniques temporarily to mitigate the health hazard should storage volumes be inadequate to serve the community. Emergency conservation and public education of the situation could be instituted to stretch available supplies. A utility would be wise to have such a contingency plan developed to ensure quick and accurate implementation.

Table 41 describes the arrival time, leave time, the number of days with contamination, the peak concentration and day of the peak concentration to each utility during the carbon tetrachloride episode simulated by QUAL-II. A 60-ton discharge is assumed to have occurred during low flow with no volatilization occurring. All the times listed in the table represent the number of days after the discharge occurred.

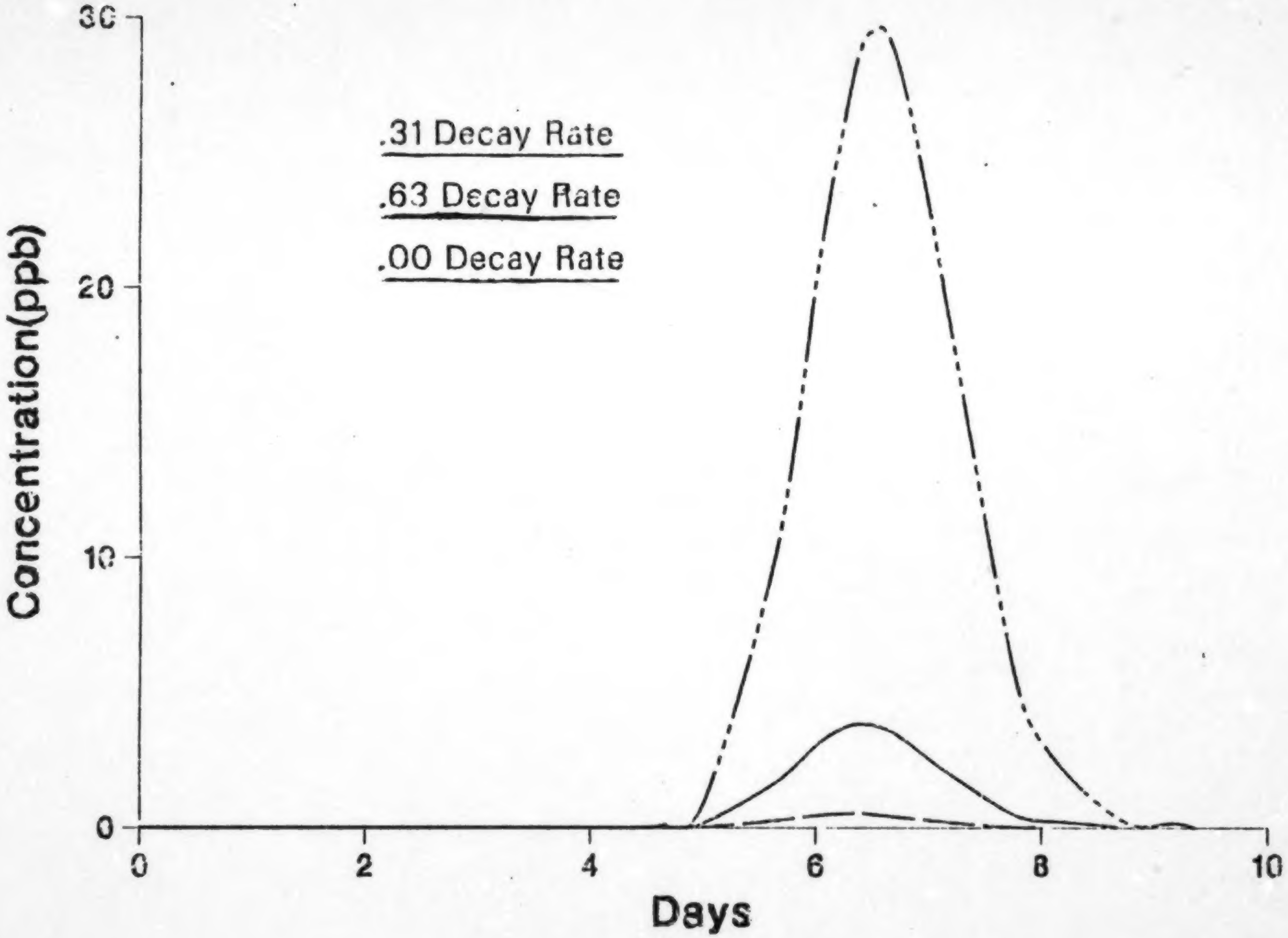

Figure 11. Priority Pollutant Concentrations at Cincinnati, Ohio with Various Decay Rates

TABLE 41

CARBON TETRACHLORIDE DISHCARGE SIMULATION

(60 ton spill at low flow)

(0 volatility)

	Arrival Time (days)	Leave Time (days)	Days with Contamination	Peak Day	Peak Concentration (ug/L)
Gallipolis	2.67	16.99	14.32	7.51	228.92
Huntington	4.51	19.98	15.47	10.02	209.29
Ashland	5.34	21.14	15.80	11.18	173.35
Ironton	5.84	21.97	16.13	11.85	169.41
Greenup	6.34	22.64	16.30	12.51	165.84
Portsmouth	7.35	24.13	16.78	13.84	149.12
Maysville	10.35	29.25	18.90	17.49	136.37
Cincinnati Area	14.00	34.50	20.50	21.97	111.39

As can be seen in Table 41 the carbon tetrachloride discharge takes two to three weeks to pass completely by each of the utilities (column 4). The peak concentrations are well in excess of the 4 ug/L level used in the Water Quality Criteria Guidelines for chronic exposure to carbon tetrachloride (Table 11). However, this exposure would only last a few days whereas the chronic exposure risk level is for developing cancer over the course of a lifetime.

The toxicity from acute exposure to carbon tetrachloride in animals has been documented extensively. Most cases dealing with human toxicity present the data in narrative form and is of little quantitative value. An epidemiological study of communities along the Ohio River following the carbon tetrachloride incident found some level of association between liver ailments and carbon tetrachloride exposure (Sonich, 1982). Oral poisonings from acute exposure to carbon tetrachloride have resulted from accidental or suicidal ingestion. Following ingestion of carbon tetrachloride the person may experience a burning sensation in the mouth, esophagus and stomach. Abdominal pain, nausea and vomiting follow. Diarrhea, which later may be followed by constipation and occasionally by gastric and intestinal hemorrhage occurs next. Depending on the dose along with other factors, the person may become jaundiced and the liver becomes enlarged and tender. The persom may suffer from headaches, dizziness and become confused. Some people may complain of restlessness and visual disturbances. In some cases, chronic alcoholism may render the individual much more susceptible. The liver, kidney and lungs are the focus of most toxicity, although other organs have been affected (Sax, 1975).

Of course, the above symptons are from acute exposure (a single dose of very high concentration (e.g. 1,000 ppm). Chronic exposure typically is defined as low exposures exceeding 6-months (Sonich, 1982). However, the emphasis in discussing the vulnerability of communities to the priority pollutants for both spills and daily discharges may lie somewhere in between chronic and acute exposure. This exposure is called subchronic and is defined in rodent studies as extending between two weeks and somewhat more than 90 days. This type of exposure may occur following a massive spill or succession of spills that may take many days to pass a utility's intake far exceeding its storage capability. Also, during seasonal periods of sustained low flow, pollutants of low volatility may increase to levels comparable to a spill, plus small spills may take on greater significance. Repeated daily exposures to such concentrations may result in systemic poisoning. Prolonged exposure may result in kidney lesions, liver degeneration or cirrhosis. When recovery takes place, there may or may not be permanant disability.

The 100 to 200 ug/L concentrations exhibited at the utilities shown in Table 41 may not be enough to create a burning sensation in the mouth, esophagus, or stomach upon ingestion but, over the course of a few days could damage or weaken organs making them susceptible for further problems in the future. If 4 ug/L are considered a proper level to be considered for chronic exposure, levels 25 to 50 times that should be a matter of great concern to utilities if only for a few days at a time. Neither the utility officials or regulatory agencies know the true number or magnitude of discharges of potentially lethal wastes flowing downstream and this potential for disaster might encourage some type of water treatment technology to be in place at all times.

The installation of GAC would provide a constant buffer against spills, thus, making the community less dependent on the detection of upstream spills. GAC would also have the benefits of removing the THM's and reducing taste and odor problems from normal daily discharges allowed by law.

Predicting Peak Downstream Concentrations

In the event of a spill, few utility managers are going to be able to access a large computer and have QUAL-II produce an answer as to the concentration of the particular pollutant that was spilled as it passes by the utility's intake. Based on numerous computer simulations using QUAL-II in the case study area, the peak concentration of a spilled pollutant at a utility can be predicted by the following equation (N=296).

$$\text{Peak} = -.74268 \div .04236 \times \text{Init} \times e^{-\text{VOL} \times \text{TOT}} \qquad (R^2 = .93)$$

where

Peak = peak concentration of the pollutant in ppb,
Init = initial concentration of the spill in ppb,
VOL = volatility of the pollutant in 1/day,
TOT = time-of-travel of the pollutant to the utility in days.

Of course certain information must be available to the utility manager, most of which can be supplied by ORSANCO, which is the agency that receives spill reports. ORSANCO has established procedures in the event of a spill that includes the following:

- The commission to the extent possible will notify downstream agencies or water users of the time and place of discharge, type and quantity of material spilled, probable in-stream concentration and time-of-travel.

Instructions for calculating time-of-travel and initial concentrations of the spill are available from ORSANCO, thus the utility manger if given the size of the spill and flow in the river could calculate by hand the variables needed in the equation.

Volatility of the pollutant is the final parameter to be considered. There is little actual information on how the priority pollutants decay as they travel downstream. Volatilization rates are presented in Appendix A based on Maybey et al., 1978. Given that the pollutant is known, it should be possible to know whether the pollutant is at least very volatile, slightly volatile or conservative. The utility manager could then make several calculations incorporating a range of decay rates. In this way, the utility manager would have a general idea as to when the spill will reach the utility and if the level of concentration is of any concern requiring extra water treatment or closure of the intakes. The equations were derived from QUAL-II simulations for the Ohio River, but the technique could possibly be applied to other large rivers.

CHAPTER V

SUMMARY AND CONCLUSIONS

The main contribution of this research has been the development of an interactive systems analysis approach that can have an impact on public policy in drinking water. Recent investigations suggest that much technological manipulation of the environment produces new hazards while ameliorating old ones, and that effective means for coping with these events calls for a sensitive understanding of natural phenomena as altered by man's actions. In studying these interactions it was necessary to bring together a myriad of information and procedures and knit them into an areal framework that can solve problems in a spatial context.

This study has been organized into a functional region. The region, although only a portion of a watershed, serves as the source of drinking water for over 1.1 million people. The defining of this region as being worthy of study is based on the perception that this is an area of risk. That hazard exist in this watershed is shown by the carbon tetrachloride episode in February, 1977. This risk to communities is a result of the gap that potentially exists between public health considerations and water pollution control strategies.

The water quality simulation model, QUAL-II, was the mechanism that brought together the diverse elements of mathematical modeling, fluid dynamics, epidemiology, organic chemistry and geography. QUAL-II although less flexible in simulating various flow scenarios and less elegant in modeling dozens of built-in parameters and biological and chemical transformations than other models such as EXAMS, exhibits a spatial organization that is totally lacking in EXAMS. Each data element was assigned a river mile location and schmatically organized in an areal context. QUAL-II has traditionally been used to model the typical parameters such as BOD, DO, temperature, etc. In this analysis, QUAL-II was used to go a step further in simulating toxic pollutants. First order decay coefficients were calculated from other sources and inserted into the model to estimate the behavior of priority pollutants in surface waters.

Specifically, this study concentrated upon the type and quantity of pollutants discharged into the Ohio and Kanawha Rivers and water utilities using those rivers as their source of drinking water between Charleston, West Virginia and Cincinnati, Ohio. Because the number of toxic and carcinogenic pollutants are so great and their impact on human health is important, a method to assess the vulnerability of communities to these pollutants in the drinking water is necessary.

Important factors to consider based on this analysis include: flow characteristics of the source of supply, potency and persistence of pollutants, amount and timing of discharge of pollutants, storage time of utilities and relative location of point sources and water utility intakes.

A. Risks Due to Daily Discharges

1. Organoleptic Pollutants - Only two of the eleven organoleptic pollutants exceed a level where sensitive consumers could be affected by taste and odor problems. Those two pollutants are 2-chlorophenol and 2,4-dichlorophenol. Only during the low flow scenario were these pollutants of any concern to the utilities. The utilities affected include Ironton, Greenup, Portsmouth, Maysville, Cincinnati, Kenton County and Newport.

2. Toxic Pollutants - During low flow periods the sensitive consumers of all the utilities would be affected by cadmium. Ashland consumers would also be affected by mercury and Greenup would have to deal with lead and chromium in addition to cadmium. The simulated concentrations of mercury exceed the criteria guideline for all consumers at Ironton, Greenup, Portsmouth, Maysville, Cincinnati, Kenton County and Newport utilities during low flow. Due to greater dilution of the pollutants at high flow, only mercury remains a concern to the utilities. During a high flow period, mercury would only affect the sensitive consumers for the seven utilities mentioned above. At average flow, cadmium and mercry exceed the guidelines for sensitive consumers at the same utilities. Throughout this analysis mercury remains a problem at various levels for all flow scenarios. Simulated cadmium, lead and chromium concentrations would affect sensitive consumers only during low and average flow scenarios.

3. Carcinogenic Pollutants - Based on the simulated concentrations of carcinogenic pollutants and their associated risk levels of developing cancer over a lifetime, the number of deaths per 100,000 people that could be expected for each community was calculated. Death rates ranged from 0.02/100,000 at Gallipolis to 6.47/100,000, at Greenup during the average flow scenario. Little is known about the concentration of pollutants entering the case study area from upstream, thus zero concentration was assumed. This probably underestimates concentrations at Gallipolis, Huntington, Ashland

and Ironton. More importantly, however, are the discharge levels used in the simulations. The flow data for the industries discharging into the Ohio River is nearly ten years old and probably not reflective of current levels given the economic conditions of Ohio River Valley industries. Also, the priority pollutant discharge concentrations assigned to each industry reflect values that could be expected if Best Available Tecnhology (BAT) is installed. Current discharge concentrations could exceed the values used greatly. In addition, each industry depending on its particular production proess will have its own unique westestream and discharge concentration. Thus, the expected number of deaths in this analysis are reflective only of what could be calculated.

The real importance in these simulations lies in the identification of the most important factors affecting water quality and their interaction. The ranking of "most vulnerable to "least" vulnerable utility changes little at various flow scenarios. However, individual pollutants did reflect the interaction of decay rates and time-of-travel. This was evident in that the most downstream utilities of Maysville, Cincinnati, Kenton County and Newport are at lower risk at low flow than at higher flows due to pollutants having more time to decay during the slow journey downstream at low flow.

B. Risks Due to Spills

The simulation of the carbon tetrachloride spill further highlighted the interaction between flow, decay rate and relative location of industries and utilities. Each utility in the case study area was shown to be vulnerable to the carbon tetrachloride spill. At low flow the spill took between two and three weeks to pass completely by each utilities' intake. No system has the equipment in place to mitigate the spill concentrations in the finished drinking water. The best the utilities could do would be to close the intakes around the time when the peak concentration would pass, thus subjecting the consumers to lower concentrations of carbon tetrachloride and not the very high peak concentrations. In the event of a spill, the less volatile pollutants will exhibit higher concentrations and longer times of passage by the intakes. However, during high flow periods the difference in concentrations between volatile and conservative constitutents will be minimzed due to the short time-of-travel downstream not allowing any decay to occur.

C. Predicting Peak Downstream Concentrations

Based on numerous QUAL-II simulations it was possible to develop an equation to predict the peak concentration of spilled pollutants. The most important variables as expected were the initial concentration of the spill, the decay rate of the pollutant and the time-of-travel. Although the equation was developed from Ohio River data, applying the form of the equation to other rivers could be an interesting avenue for further research.

D. Research Extensions

The first and most obvious extension of this type of analysis would be to tie it to a detailed sampling program in order to establish accurate background levels of pollutants. Next, data accurately reflecting the discharge flow and concentrations of the industries in question should be obtained.

Another extension of this methodology would be to incorporate it into benefit-cost analyses. Simulations could be performed using current discharge levels to assess present risks to communities. Simulations could then be done using concentrations reflective of new technology reducing wastewater contamination. The new risk levels could be compared to the cost of the new technology resulting in fewer expected deaths.

Using this methodology, there exists a potential for a substantial shift in the emphasis of the Clean Water Act. The Clean Water Act has not presented anywhere near the type of potential obstacles in preventing siting of industrial facilities as has the Clean Air Act. Typically, water pollution controls have affected how a new plant is to be built, but they have not altered questions of whether or where a new plant is built. The legal framework for the Clean Water Act appears to lay the same type of foundation upon which the nonattainment preconstruction review program was developed for new sources of air pollution under the Clean Air Act. However, no system has evolved under the water pollution statutes to provide this review.

A partial explanation may be that violations of the air quality standards present a direct threat to human health, whereas the water quality standards have focused more on protection of aquatic life. A further possible explanation may be that the Clean Air Act is entirely concentrated on achievement of the air quality standards. The principal emphasis of the water pollution control effort has focused on applying technological standards to existing sources (Quarles, 1979).

The methodology employed in this analysis emphasizes the human health feature of water quality and looks at a watershed similar to the "Bubble" concept now being used in air quality regulations. The revised NPDES regulations recently proposed by EPA states that no permit shall be issued to a new source or discharger if it will cause a violation of the water quality standards. NPDES permit limitations are established on water quality standards, but very few specific organics (toxics) are written into these permits. In order for the NPDES permitting system to be effective, specific organic compounds should be included that are indicative of each industries' particular discharge. The burden of proof would be on the permit applicant and that there would be a sufficient remaining pollutant loading allocations to cover the new discharge. This study sets the stage for application of the same type of offsets policy as was developed in the nonattainment program under the Clean Air Act (Quarles, 1979).

As the Water Quality Criteria Guidelines are developed, refined and possibly become law, this methodology simulating concentrations would be directly applicable to the fulfillment of the regulations. A particluar industry would only be interested in simulating a few relevant pollutants, whereas the downstream utilities would be concerned with the total upstream pollutant load. There could be many duplications of effort, thus the study would seem to be more aptly a management tool of river basin compacts or regional authorities. The responsible agency could have a model on-line and properly calibrated for their river or rivers in question for quick analysis of new NPDES permit applications or community concerns about upstream dischargers or spills making that community vulnerable and subject to regulations requiring additional water treatment technology such as GAC filtration.

In conclusion, it is important to realize the importance that ample supplies of good quality natural resources have on the economy and quality-of-life. Water supply shortages may not be solely a quantity problem, but may involve quality considerations. Large supplies of contaminated water are of no use and represent potentially significant clean-up costs as well as health risks. Proper management of our environment is a responsibility we must accept for future generations.

BIBLIOGRAPHY

1. Alavanja, Michael; Goldstein, Inge; and Susser, Mervyn, "A Case Control Study of Gastrointestinal and Urinary Tract Cancer Mortality and Drinking Water Chlorination," paper presented at Conference on Water Chlorination: Environmental Impact & Health Effects, Gatlinburg, Tennessee, October 31, 1977.

2. American Cancer Society, *1981 Cancer Facts and Figures*, New York City, New York, 1981, p.3.

3. Arbuckle, J. Gordon, *Environmental Law for Non-Lawyers*, Bethesda Government Institutes, Inc., 1979.

4. Bellar, T. A., et al., "The Occurrence of Organohalides in Chlorinated Drinking Waters" Environmental Protection Agency, Envrionmental Monitoring Series, 1974.

5. Buncher, Ralph C.; Kuzma, Ronald J.; and Kuzma, Cecilia M., "Ohio Drinking Water Sources and Cancer Rates," *American Journal of Public Health*, Vol. 67, 1977, pp. 725-729.

6. Carlson, William S., and Andelman, Julian B., "Environmental Influences on Cancer Morbidity in the Pittsburg Region," USEPA, Health Effects Research Laboratory, Cincinnati, Ohio, EPA/CA-6-99-3379-J., April, 1977.

7. Clark, Robert M. "The Safe Drinking Water Act: Its Implications for Planning." *Municipal Water Systems - The Callenge for Urban Resource Management*. David Holtz and Scott Sebastian (eds.). Holcomb Research Institute, Indiana University Press, Bloomington, Ind., 1978.

8. Council on Environmental Quality, *Environmental Quality-1979, The Tenth Annual Report of the Council on Environmental Quality*, Washington, DC., U.S. Government Printing Office, December, 1979, pp. 76-78.

9. Dallaire, Gene, "Are Cities Doing Enough to Remove Cancer Causing Chemicals from Drinking Water?", *Civil Engineering, ASCE, Series on Water Resources*: No. 1, September, 1977.

10. Dames & Moore, *Assessment of the Impacts of PL 92-500 on the Ohio River Basin for the National Commission on Water Quality*, Volume 1, Cincinnati, Ohio, November, 1975.

11. Daum, Richard M., *Quarterly Report for October-December, 1980*, Technical Support Division, Office of Drinking Water, Office of Water and Waste Management, Environmental Protection Agency, Cincinnati, Ohio, February, 1981.

12. Dawson, G. W.; Shuckrow, A. J.; and Swift, W. H., Control of Spillage of Hazardous Polluting Substances, U.S. Federal Water Quality Administration, Program No. 1509, PF-7, Washington, D.C., 1970, p. 55.

13. Environmental Protection Agency, "Statement of Basis and Purpose for an Amendment to the National Interim Primary Drinking Water Regulations on a Treatment Technique for Synthetic Organic Chemicals," Office of Water Supply, Environmental Protection Agency, Washington, D.C., 1977.

14. _______, "Interim Primary Drinking Water Regulations: Control of Organic Chemical Contaminants in Drinking Water," Environmental Protection Agency, Washington, D.C., 1978.

15. Federal Register, "Environmental Protection Agency Interim Primary Drinking Water Regulations," Vol. 43, No. 28, Thursday, February 9, 1978, pp. 5756-5780.

16. _______, "National Interim Primary Drinking Water Regulations: Control of Trihalomethanes in Drinking Water, Final Rule," Vol. 44, No. 231, Thursday, November 29, 1979, p. 68698-68707.

17. _______, "National Revised Primary Drinking Water Regulations, Volatile Synthetic Organic Chemicals in Drinking Water, Advanced Notice of Proposed Rulemaking," Vol. 47, No. 43, Thursday, March 4, 1982, pp. 9351-9353.

18. Heuper, W. C. and Conway, W. D., Chemical Carcinogenesis and Cancer, Charles C. Thomas, Springfield, 1964.

19. Hitch, Charles J., Introduction to Paul G. Rodgers in Safe Drinking Water: Current and Future Problems, Proceedings of a National Conference in Washington, D.C., Clifford S. Russell, ed., Research paper R-12, Washington, D. C., Resources for the Future, 1978, pp. 1-3.

20. Ireland, John C.; Warner, H. Paul; and Cohen, Jesse N., "Determination of Henry's Law Constants of Selected Priority Pollutants," Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, April 1980, pp. 7-13.

21. Kroner, Robert C., "Accidential Chemical Spills, A Review of Incidents in the Ohio River Valley, 1978 and 1979," Public Works, October, 1980, pp.48-50.

22. Lieber, Harvey. Federalism and Clean Waters. Lexington, Mass., D.C. Heath and Co., 1975, pp. XIII.

23. Love, O. Thomas Jr., and Eilers, Richard G., "Treatment of Drinking Water Containing Trichloroethylene and Related Industrial Solvents," Journal of the American Water Works Association, August, 1982, pp. 413-425.

45. Malcolm Pirnie, Inc., Volatile Organic Chemicals in Ground Water Workshop Notebook, Paramas, N. J., September 1, 1982.

25. Mabey, W. R., et al., "Aquatic Process Data for Organic Priority Pollutants," Final Draft Report, Michael W. Slimak, Project Officer, Monitoring and Data Support Division, Office of Water Regulations and Standards, U.S. Environmental Protection Agency, Washington, D. C., July, 1981, pp. 409-434.

26. McDermott, James H., "Federal Drinking Water Standards - Past, Present, Future," Journal of the Environmental Engineering Division, ASCE, Vol. 99, No. EE4, Proceedings Paper 9924, August, 1973.

27. McPhillips, T. J., Personal Correspondance, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Cincinnati, Ohio, December, 1982.

28. Mills, W. B., et al., Water Quality Assessment: A Screeing Procedure for Toxic and Coventional Pollutants - Part 1, Center for Water Quality Modeling, Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, Georgia, EPA-600/6-82-004a, September, 1982, pp. 1-42.

29. National Academy of Science (NAS), "Summary Report: Drinking Water and Health," Safe Drinking Water Committee, NRC, NAS, Washington, D.C., 1977.

30. National Organics Monitoring Survey (NOMS), EPA Office of Water Supply, 1977.

31. Ohio River Valley Water Sanitation Commission, Report and Notification of Spills and Accidental Discharges, Cincinnati, Ohio, July, 1978, pp. 1-3.

32. Page, T.; Harris, R. H.; and Epstein, S. S., "Drinking Water and Cancer Mortality in Louisiana," Science, Vol. 193, No. 4247, July 2, 1976, pp. 55-57.

33. Page, Talbot; Harris, Robert; and Bruser, Judith, "Removal of Carcinogens from Drinking Water: A Cost-Benefit Analysis," Social Science Working Paper 230, Division of the Humanities and Social Sciences, California Institute of Technology, Pasadena, California, January, 1979.

34. Quarles, John, "Federal Regulation of New Industrial Plants, "Environmental Reporter, Monograph No. 28, Vol. 10, No. 1, May 1, 1979.

35. Roesner, Larry A.; Giguere, Paul R. and Evenson, Donald E., Computer Program Documentation for the Stream Quality Model QUAL-II, Center for Water Quality Modeling, Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, Georgia, EPA 600/9-81-014, February 1981.

36. Rook, J. J., "Formation of Haloforms During Chlorination of Natural Waters," Journal of Society of Water Treatment and Examination, Vol. 23, 1974, pp. 234-236.

37. Sax, N. Irving, Dangerous Properties of Industrial Materials, New York City, New York, Von Nostrand Reinhold Company International, Litton Educational Publishing, Inc., 1975.

38. Sonich, Cynthia, Personal Conversation, Office of Research and Development, Environmental Criteria Assessment Office, U.S. Environmental Protection Agency, Cincinnati, Ohio, November, 1982.

39. Starr, Douglas, "Cancer in Cincinnati: Testing the Water," The Cincinnati Post, second of eight parts, Monday, November 17, 1980, p. 1.

40. Stokey, Edith and Zeckhauser, Richard, A Primer for Policy Analysis, New York City, New York, W. W. Norton & Compnay, 1978, pp. 8-21.

41. Symons, James M., et al., "National Organics Reconnaissance Survey for Halogenated Organics," Journal of the American Water Works Association, Vol. 67, 1975, p. 634.

42. Tyler, Patrick E. "After 30 billion, No One Knows if Nation's Water Is Any Cleaner." The Washington Post, Thursday, May 14, 1981, p. A2.

43. United States Army, Corps of Engineers, HEC-2 Water Surface Profiles - Users Manual, Davis, California, The Hydrologic Engineering Center Computer Program, 723-X6-L202A, August, 1979.

44. United States Office of Management and Budget, Statistical Policy Division, Standard Industrial Classification Manual, Washington, D.C., U.S. Government Printing Office, 1972.

45. West Virginia Department of Natural Resources, Basin Water Quality Management Plan for the Kanawha River Basin, December, 1975.

46. Zajic, J. E., and Himmelamn, W. A., "Environmental Effects of Spills," Highly Hazardous Materials Spill and Emergency Planning, New York City, New York, Marcel Dekkar, Inc., 1978, pp. 36-69.

APPENDIX A

WATER QUALITY MODEL SELECTION

The term "Model" can mean many things to many people. A model is a simplified representation of some aspect of the real world. It is a purposeful reduction of a mass of information to a manageable size and shape (Stokey and Zeckhauser, 1978). In this analysis a set of equations in a spatial context was represented by QUAL-II.

The selection of the "right" model depends on the type of situation, answers desired, level of detail needed and variables that can be controlled. The model should be judged by how well it works or how accurately it predicts. Great care must be taken with the assumptions that drive a model in order that accuracy be obtained.

A variety of water quality models were considered. Those evaluated include the following: QUAL-II, WQRRS, HSPF, RECEIVE-II, STREAM and EXAMS. The most important characteristics considered in model selection were hydraulic regime, parameters modeled, data requirements and ease of use.

Hydraulic Regime

Water routing models are ususally described as "steady state" or "Dynamic". Steady state models such as QUAL-II and EXAMS assume that $\partial Q/\partial t = 0$ where,

Q = discharge in cubic feet per second and

t = time.

Thus, hydraulically QUAL-II and EXAMS are limited to the simulation of time periods during which stream flows in the river basin are essentially constant which may or not be critical. Because of its size and lock and dam system, the Ohio River does not exhibit the rapid and sudden fluctuations of smaller streams thereby making this requirement less critical.

WQRRS, HSPF and RECEIVE-II have dynamic water routing capabilities to handle temporally gradually varied steady and unsteady stream regimes, peak flows from stormwater runoff, hydropower releases or tidal changes in estuaries. However, these added features require more data inputs, user sophistication and computer time often costing hundreds of dollars per computer run. HSPF was eliminated from consideration at this point due to lack of documentation because of its recent development and over 75,000 cards of source program. STREAM was no longer considered since it operated conceptually at pooled river stage.

Water Quality Parameters

All of the remaining models simulated many of the same traditional parameters such as BOD, DO, nitrogen, phosphorous and conservative constitutents. Only EXAMS specifically simulated toxic organic substances involving much detailed information the user must supply. QUAL-II simulated the traditional parameters as well as allowing for a user specified non-conservative constituent using first-order decay rates. Although WQRRS simulated far and above the most parameters including fish, pH and benthic organisms it did not have QUAL-II's flexibility for arbitary parameters. EXAMS was geared for organic substances but due to its youth, only 11 specific and one user specified compound could be accommodated.

Date Requirements and Ease of Use

At this point EXAMS is no longer considered. The calculations of the rate of change of the organic compounds modeled by EXAMS requires data on volatilization, direct photolysis, sensitized photolysis, hydrolysis, breakdown by photoautotrophs, microbial degradation and sediment exchange. Such information is extremely difficult to get and of questionable utility for many of the pollutants. Only volatility has a body of literature analyzing rates which is limited also.

Although QUAL II is bulky in altering flow scenarios since it is a steady state model, QUAL-II's structure and data requirements made it the chosen model. An advantage of using models is to discipline one's thinking and focus attention on the fundamental principles. QUAL-II provided a bookkeeping mechanism - each industrial discharge, tributary and utility intake had to be assigned a unique river mile location described in Figure 6. This schematic representation simplified thnking and highlighted critical variables such as relative locations of utilities and dischargers and time-of-travel, thus being intuitively appealing to spatially oriented modelers. EXAMS did not simulate rivers with milepoints but simulated pollutants in half-lives or concentrations for ecosystems described as simply a large river.

Calculation of Decay Rates

In assessing the aquatic fate of pollutants, there are three levels of refinement, each in order of increasing complexity. They are:

1) Treating the pollutant as a conservative substance,
2) Considering transport process, and
3) Considering transformation, transport and speciation processes.

The simplist approach to estimating the concentration of a toxic pollutant is to assume it behaves conservatively (i.e. does not undergo reaction). The obvious advantage of this approach is that it requires no chemical or environemtal data. The only data needed are pollutant loads and hydrological parameters. The metals and inorganic pollutants can be simulated in this way.

The second approach requires more information on the properties of the toxicant and the environment then when the pollutant is assumed to behave conservatively. Because of the importance of tranport processes which include volatilization, this is a good intermediate step between the simplist and most complicated approaches.

The most complex model one can employ includes the consideration of chemical processes that alter the compounds in addition to the above transport process. The inclusion of the degradative processes (i.e., biodegradation, photolysis and hydrolysis) considerably increase the chemical and environmental data required to model a compound's fate (Mills et al., 1982). Rather than include all the constants for the above processes, the modeler should determine which processes are relevant to each compound. For the volatile organic chemicals, volatilization is the dominating process and further detail would not be necessary or increase accuracy significantly.

As such, the simulation of these pollutants are highly dependant on specifying a volatilization rate that reflects the particular pollutant. Other pollutants can be treated as conservative constituents depending solely on advection and dispersion to alter concentrations as they travel downstream.

Volatilization of an organic chemical from water is a first-order rate process (Maybay et al., 1981). Volatilization rate constants were estimated by Maybey et al. utilizing a variety of methods. The Henry's Constant was observed to be the critical variable in those estimates. Henry's Constant is an expression of the distribution of a volatile solute at equilibrium between the liquid and vapor phases (Ireland et al., 1980). The value of Henry's constant determines the volatilization rate constant while the size of molecule which affects other diffusion coefficients is much less significant. Maybey et al. calculated the volatilization rate constants based on the pollutants' Henry's Law Constant holding the other parameters steady. These rates were used in the following equation in QUAL-II to simulate the priority pollutants (Roesner, 1981):

$$\frac{\partial R}{\partial t} = \frac{\partial(A_x D_L \partial x)}{A_x \partial x} - \frac{\partial(A_x u R)}{A_x \partial x} \pm \frac{S_R}{A_x dx} - KR$$

where

R = the concentration of the priority pollutant in ug/L,

K = decay rate for the pollutant in 1/day,

t = time in days,

A_x = cross-sectional area in ft^2,

D_L = dispersion coefficient in ft^2/t,

x = distance in feet,

u = velocity in feet per second, and

S = external sources or sinks of pollutant in ug/L.

As more data on the priority pollutants are gathered, the most important physical and chemical charteristics of toxic compounds that govern the fate of the pollutants can be identified and utilized to assign a more accurate decay rate. For the priority pollutants this will probably involve direct photolysis and bioaccumulation in addition to volatilization (Mills et al., 1982).

For each non-conservative priority pollutant a decay rate was specified to calculate the downstream concentration based on the previous first-order decay equation. Comparison of QUAL-II's simulated concentrations can only be verified and calibrated by detailed sampling data throughout the case study area which is not presently available. However, QUAL-II results correspond well with observed values at Cincinnati Area intakes during the carbon tetrachloride episode. Time-of-travel estimates compare favorably with ORSANCO nomographs for various flows also, thus lending credibility to the simulated results for the volatile compound concentrations which are very dependent on the time-of-travel.

Table A-1 lists the priority pollutants and the decay rates utilized in QUAL-II derived from Maybey et al.

TABLE A-1

CALCULATED DECAY RATES FOR PRIORITY POLLUTANTS

Priority Pollutant	Pollutant Number	Decay Rate (1/day)
Pesticides		
Acrolein	1	.1000
Aldrin	2	.0500
α-BHC	3	.0200
β-BHC	4	.0007
γ-BHC	5	.0250
DDE	9	.3800
Dieldrin	11	.0000
α-Endosulfan	12	.0550
Endrin	15	.0010
Heptachlor Epoxide	18	.4500
Metals and Inorganics		
Antimony	22	.0000
Arsenic	23	.0000
Berrylium	25	.0000
Cadmium	26	.0000
Chromium	27	.0000
Copper	28	.0000
Cyanides	29	.0000
Lead	30	.0000
Mercury	31	.0000
Nickel	32	.0000
Selenium	33	.0000
Silver	34	.0000
Thalliam	35	.0000
Zinc	36	.0000
PCB's		
PCB-1221	38	.3800
PCB-1232	39	.0500
PCB-1242	40	.5300
PCB-1248	41	.5400
PCB-1254	42	.5500

TABLE A-1 (Cont'd)

Priority Pollutant	Pollutant Number	Decay Rate (1/day)
Halogenated Aliphatics		
Chloromethane	46	.6100
Dichloromethane	47	.5500
Chlorodibromomethane	48	.4000
Dichlorobromomethane	49	.5500
Tribromomethane	50	.4600
Chloroform	51	.5500
Carbon Tetrachloride	52	.6300
Trichlorofluoromethane	53	.5700
Dichlorodifluoromethane	54	.6600
1,2-dichloroethane	57	.5600
1,1,1-Trichloroethane	58	.5200
1,1,2-Trichloroethane	59	.5000
1,1,2,2-Tetrachloroethane	60	.4900
TCE	65	.6100
Tetrachloroethene	66	.6100
1,3-Dichloropropene	68	.5300
Hexachlorobutadiene	69	.6600
Ethers		
Bis(chloromethyl)ether	71	.4500
Bis(2-2-chloroethyl)ether	72	.0600
Bis(2-chloroisopropyl)ether	73	.3800
Vinyl Chloride	74	.0005
Monocyclic Aromatics		
Benzene	78	.5500
Chlorobenzene	79	.5500
1,3-Dichlorobenzene	81	.5500
1,4-dichlorobenzene	82	.5500
Ethylbenzene	85	.6100
Nitrobenzene	86	.0600
Toluene	87	.6500
2,4-Dinitrotoluene	88	.0200

TABLE A-1 (Cont'd)

Priority Pollutant	Pollutant Number	Decay Rate (1/day)
Phenols and Cresols		
Phenol	90	.0250
2-Chlorophenol	91	.0550
2,4-Dichlorophenol	92	.0100
2,4,6-Trichlorophenol	93	.0250
Pentachlorophenol	94	.0100
2,4-Dinitrophenol	97	.0000
2,4-Dimethylphenol	98	.0600
4,6-Dinitro-o-cresol	100	.0700
Pthalate Esters		
Dimethyl Pthalate	101	.0070
Diethyl Pthalate	102	.0050
Dibutyl Pthalate	103	.0250
Polycylic Aromatic Hydrocarbons		
Acenaphthene	107	.2000
Acenophthylene	108	.4300
Anthracene	109	.5000
Benzo(a)anthracene	110	.0045
Benzo(ghi)perylene	113	.0006
Chrysene	115	.0050
Fluoranthene	117	.0350
Fluorene	118	.6100
Phenathrene	121	.4500
Pyrene	122	.0300
Nitrosamines		
Diphanylnitrosamine	124	.5500
Acrylonitrile	129	.2500